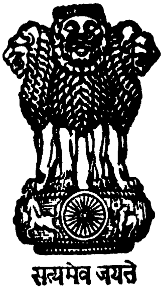

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WITH PLATES AND FIGURES

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VEGETABLE JUICES AS FIXATIVES OF ANIMAL TISSUES.

By A. Narayana Rao, B.Sc. & L. S. Ramaswami, B.Sc.
(*Department of Zoology, Central College, Bangalore.*)

In a preliminary note to *Nature* (Vol. 124, May 23, 1931) we noted the possibility of employing juices of some of the common vegetables, such as onion, tamarind, gooseberry and mango as fixatives for the animal tissues. Since then, we have extended these methods to a wide range of histological material and have found that these juices can, with great safety, be employed for the demonstration of the detailed structure of a variety of animal tissues.

Gairns (*Quarterly Journ. Micro. Sci.*, Vol. 74, Part I, September 1930) described a modification of the gold chloride method for the demonstration of nerve endings by using fresh lemon juice followed by gold chloride and formic acid. The possibility of using other vegetable juices was suggested to us by Professor C. R. Narayan Rao as also their application as tissue fixatives, both of which have yielded very gratifying results. We wish to acknowledge our indebtedness to him for his very valuable suggestions and guidance. We would also wish to express our thanks to Dr. A. Subba Rao who drew our attention to Muller's technique for the demonstration of nerve endings whose method, however, we had independently tried in our laboratory.

The following methods are employed :—

1. *For the Demonstration of Nerve Endings.*

Onion and gooseberry juices with and without formic acid (1·22 sp. gr.).

(*A*) *With formic acid :*

Three parts of the juice and one of formic acid (1·22 sp. gr.). Sufficient quantities of the mixture to completely immerse the tissue are taken. Tissues are left in the mixture for 10 to 20 minutes and after draining off the excess of the mixture by placing the tissue between the folds of clean muslin, they are transferred to 2 per cent gold chloride and kept in darkness for half an hour, and washed in distilled water; drain off the water as above. Tissue transferred to 25 per cent formic acid and kept in darkness for 24-36 hours. Transfer the tissue to glycerine after draining the excess fluid as before and the same will be ready for examination after three days.

(*B*) *Without formic acid:*

(1) Pure juice sufficient to immerse the tissue is taken. Subsequent treatment as in (A).

(2) Garlic juice. With and without formic acid. Procedure as above. Satisfactory results are obtained if 25 per cent formic acid is used in equal quantities with the juice. Garlic juice alone will give indifferent results.

(3) Tamarind, mango and pomegranate juices with and without formic acid. Treatment as above. Yields satisfactory results.

(4) Fresh cow's and human urine as a special fixative for the demonstration of nerve endings, Pacinian bodies, Meisner's and Aurbach's plexuses.

Three parts of urine and one part of formic acid (1·22 sp. gr.).

Voluntary and involuntary muscles of 10-15 mm. are selected. Immerse in the mixture for 30 minutes and wipe the tissues between folds of clean muslin. Transferred to 2 per cent gold chloride and kept in darkness for 30 minutes Wipe and transfer the tissue to freshly prepared 25 per cent formic acid and keep the material in darkness for 24-36 hours. The tissue is later transferred to glycerine and is ready for examination after three days.

(5) Citric acid (5—7½—10 per cent) and formic acid.

Three parts of citric and one of formic (1·22 sp. gr.). Treatment as above.

2. *For Histological Studies of Animal Tissues.*

(1) Fresh cow's or human urine, onion, garlic and any of the juices employed above for the demonstration of nerve endings may be employed for the histological studies of animal tissues. Fix tissues in urine (½ to 1 hour, for the study of chromosomes 2—3 hours, onion or any other vegetable juice 1—2 hours). Wash in tap water, grade up the material from 30 per cent alcohol. Two changes of absolute, clear in cedarwood oil or xylol. Two changes of paraffin before made into block. Sections stained in hæmalum or any of the standard stains.

(2) Onion juice alone may be used for the demonstration of glycogen areas of hepatic cells.

Fix small pieces of liver of a small mammal (fed on starchy food) for 1 to 2 hours in fresh onion juice. Take the material to absolute alcohol straight. Give three changes in cedarwood oil. Sections stained in Best's Carmine.

3. Treatment of glandular and ovarian tissues with onion juice and subsequent osmication with osmic acid for the demonstration of golgi and mitochondria proved futile.

It was suggested to us by Dr. A. Subba Rao that an attempt should be made to determine the active principle in the composition of the cow's urine which was responsible for the fixation of the tissue.

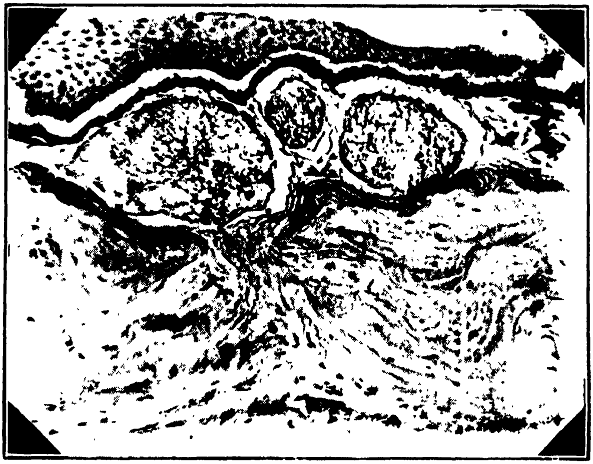
Acid hippuric which was suggested by Dr. A. Subba Rao is insoluble in cold water, soluble in warm water but readily goes into solution in the presence of a base like AmOH or NaOH, forming a hippurate. Experiments with these salt-solutions proved useless.

Ammonium bicarbonate. Neither a 5 per cent solution in water nor hippuric dissolved in a medium of ammonium bicarbonate solution yielded any satisfactory result.

At the suggestion of Professor C. R. Narayan Rao that urea might be the active principle in fixation, we tried aqueous solutions of urea in various concentrations (2—3 & 4 per cent) and the results are very satisfactory.

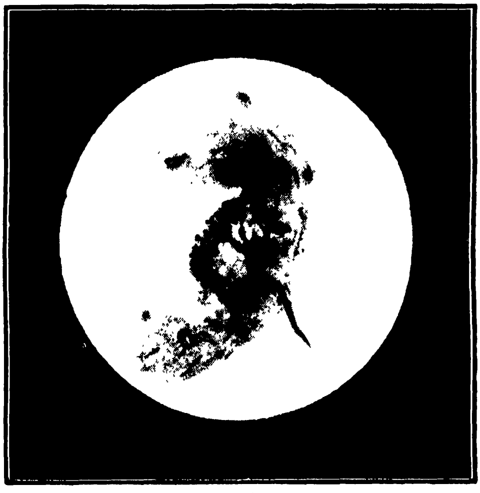
We reproduce several photomicrographs of preparations according to the methods described above.

PHOTOMICROGRAPHS



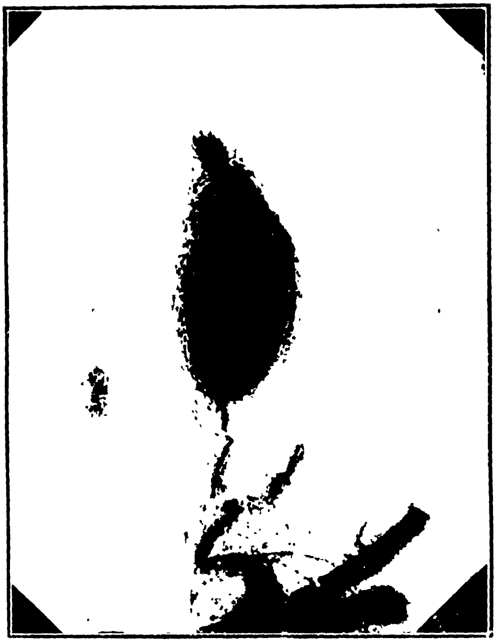
No. I.

Skin of *Rana hexadactyla*. Tissue fixed in Onion juice for 3 hours and stained with hæmalum and Eosin.



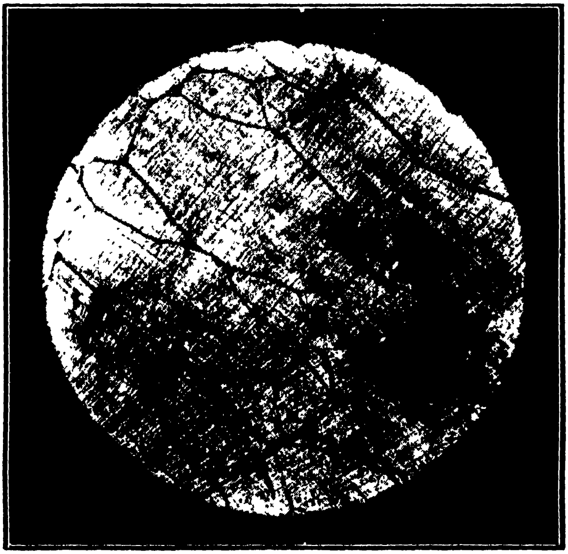
No. II.

Nerve ending in the intercostal muscle of Calotes. Fresh tissue treated with Formic acid and Onion juice (1 : 3) Sp.gr. of Formic 1·22. Kept in darkness for 10 minutes. Impregnation with 2% Gold chloride for 30 minutes in darkness. Reduced by 25% Formic acid (24-36 hours). Transferred to glycerine for examination.



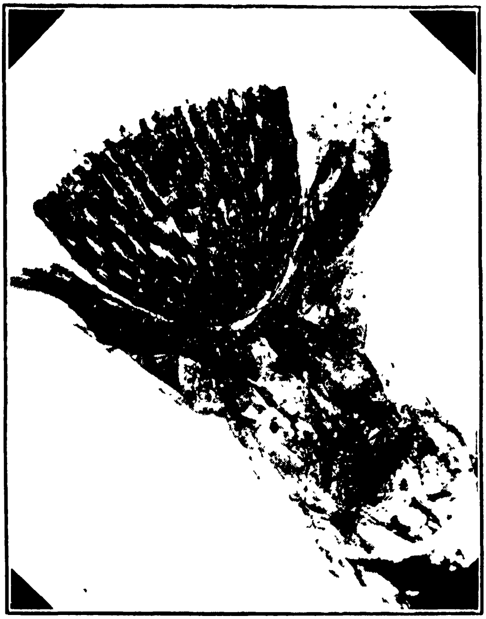
No. III.

Pacinian body from the palmar surface of Loris. Technique as in No. II.



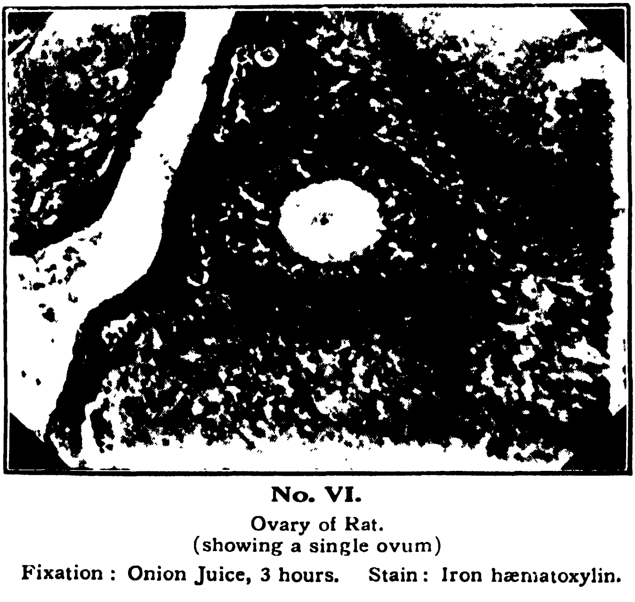
No. IV.

Nerve plexus from the intestine of Rat. Technique as in No. II.



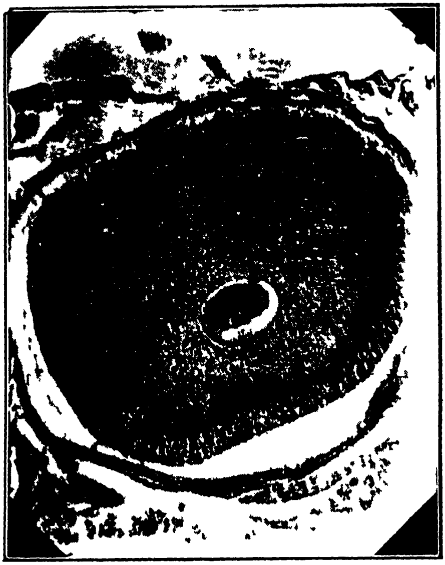
No. V.

New type of sensory organ from the mesentery of Loris.
Technique as in No. II.



No. VI.

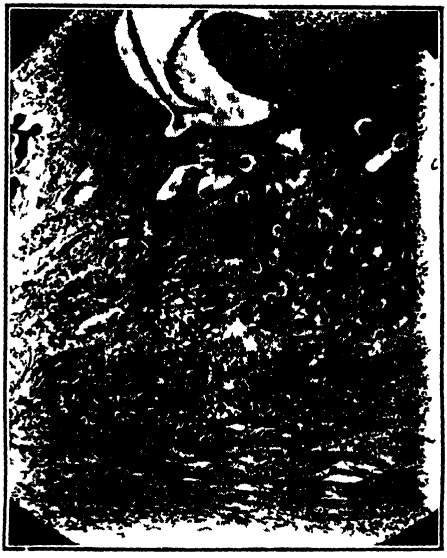
Ovary of Rat.
(showing a single ovum)
Fixation : Onion Juice, 3 hours. Stain : Iron hæmatoxylin.



No. VII.

Reptilian Ovum

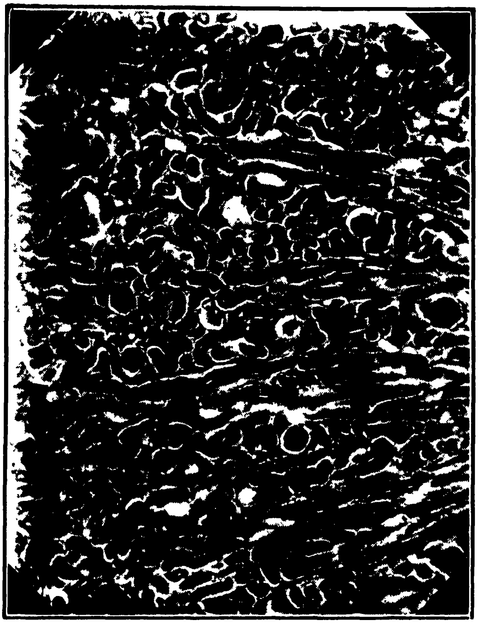
Fixed in Onion Juice Stained with Mayer's hæmalum.



No. VIII.

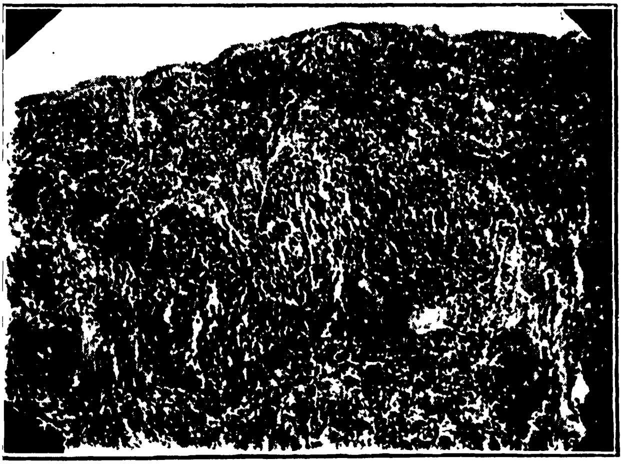
Uterus of Loris.

Fixed in Onion Juice. Stained with hæmalum.



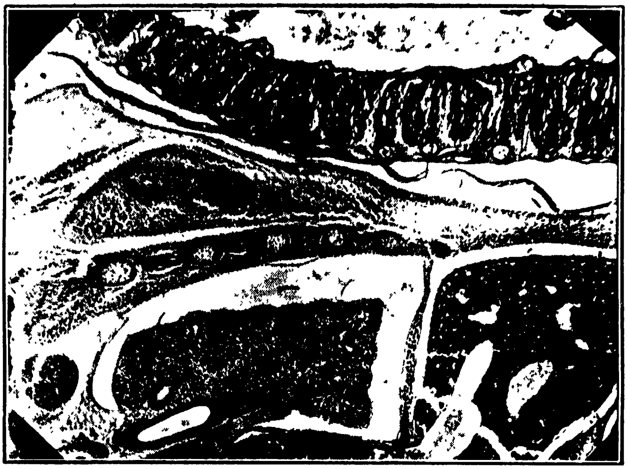
No. IX.

Kidney of Loris.
Fixed in Onion Juice, stained in hæmatoxylin.



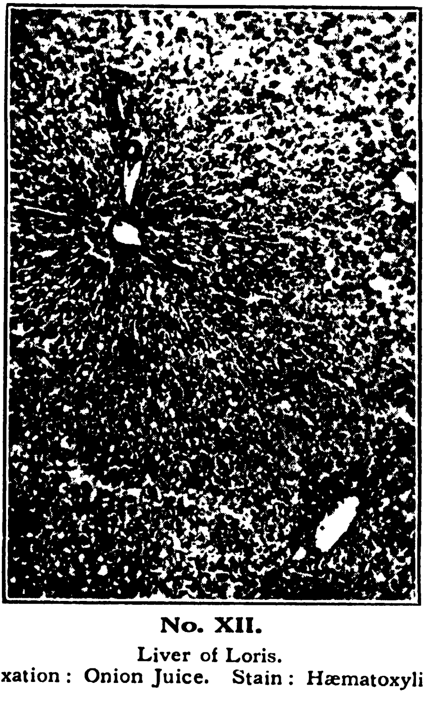
No. X.

Spleen of Loris.
Fixation: Onion Juice. Stain: Iron hæmatoxylin.



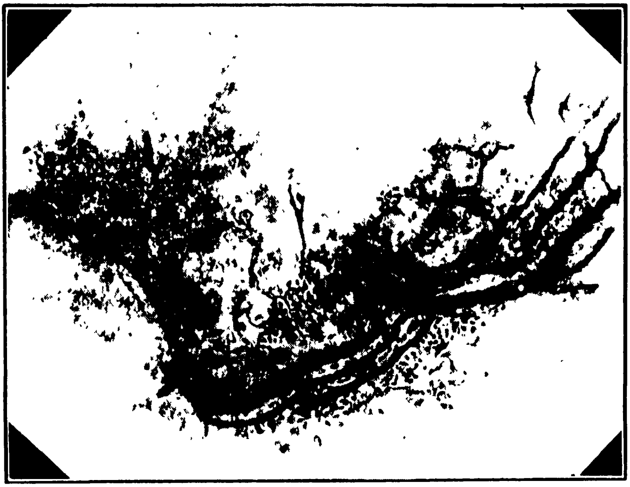
No. XI.

Placenta and a portion of the young of Bat.
Fixation: Onion Juice, 3 hours. Stain: Iron hæmatoxylin.



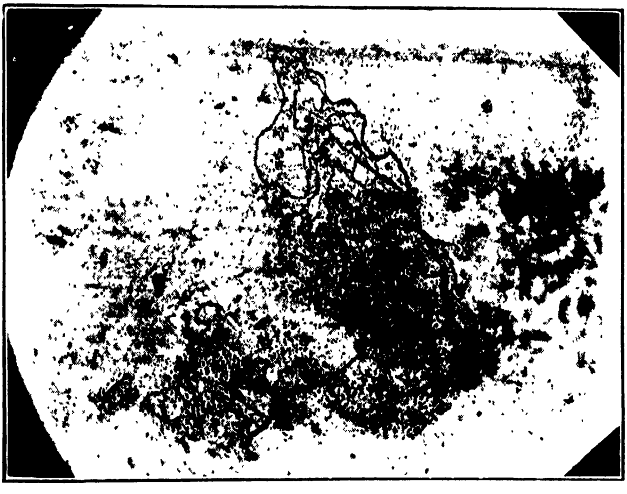
No. XII.

Liver of Loris.
Fixation: Onion Juice. Stain: Hæmatoxylin.



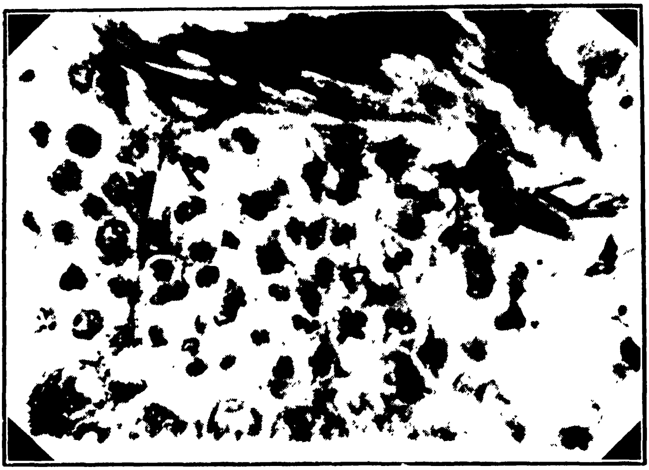
No. XIII.

Ganglion cells.
Onion-formic Gold-chloride.
(Loris)



No. XIV.

Major Nerve Ending.
Loris.
Onion-formic Gold-chloride.



No. XV.

Testis of Frog.
Fixed in fresh cow's urine, and stained in hæmatoxylin.

No. XVI.

Pacinian Body.
Palmar surface of Loris.
Onion-formic Gold-chloride.

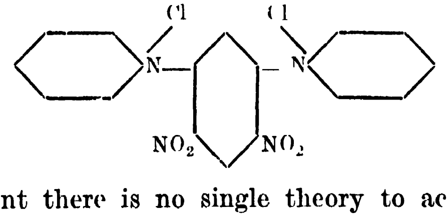
ON SOME MOLECULAR COMPOUNDS.

By H. S. Jois and B. L. Manjunath.

(*Department of Chemistry, Central College, Bangalore.*)

The molecular compounds of 4 : 6 dichloro-1 : 3 dinitrobenzene (**A**) with naphthalene, α and β naphthols, α and β naphthylamines (Sudborough and Picton, *J. Chem. Soc.*, 1906, **89**, 589-590), benzidene and pyridene, have been prepared. There was no evidence of any sort of reaction between **A** and anthracene, dimethylaniline, diphenylamine and ortho, meta and para nitranilines, even when a solution of a mixture of the components in absolute alcohol was refluxed on a water-bath.

It is interesting to note that in the case of the first five compounds, the components are present in equimolecular ratios. Unsuccessful experiments were tried to obtain compounds of **A** with these substances in the molecular ratio 1 : 2. With benzidene, however, the molecular compound formed always contained two molecular proportions of **A**. It was also attempted to prepare the molecular compound of 2 : 4 dinitrochlorobenzene with benzidene (Buehler, Hisey and Wood, *J. Amer. Chem. Soc.*, 1930, **52**, 1939) but all the usual methods were of no avail and when the carbon tetrachloride solutions of the components were mixed, a small quantity of dark crystals separated consisting of a mixture which could not be purified. With pyridene the reaction was very vigorous and it was possible to isolate from the products formed the dipyridonium salt of the following structure :



At present there is no single theory to account for the structure of the molecular compounds owing to their widely varying properties. Accepting the views of Werner (*Ber.*,

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*Cf. Jois and Manjunath, *J. Indian Chem. Soc.*, 1931, **8**, 633.

1909, **42,** 4324) and Pfeiffer (*Z. anorg. Chem.*, 1920, **112,** 90) on secondary valency linkages, Hertel and Römer (*Ber.*, 1930, **63,** 2146) have expressed certain general conceptions which will be of considerable help in classifying the organic molecular compounds into certain distinct types. The two components in a molecular compound are to be regarded as having the structures A_1—M_1—R_1 and A_2—M_2—R_2 wherein A_1 and A_2 are the "addition centres," R_1 and R_2 the reactive elements or radicals, of the molecules M_1 and M respectively.

The molecular compounds of di and poly nitro compounds and of their halogen derivatives, with hydrocarbons and phenolic compounds may be regarded as having the general formula:

$$R_1 \text{——} M_1 \text{——} A_1 \quad : \; : \; : \quad A_2 \text{——} M_2 \text{——} R_2$$

(Equation I of Hertel and Römer, *loc. cit.*)

This formula would account for the ease with which these molecules can be split up into their components.

The feeble colour of the molecular compounds of the simpler hydrocarbons belonging to the above type becomes enhanced (pale yellow to orange) in the case of the compounds of the more condensed nuclei (Pfeiffer, "Organische, Molekülverbindungen," 1922, page 222). It may be suggested that the secondary valency linkage here is not chromogenic, but when the residual affinity is neutralised, colour becomes manifest as a result of the intensification of the conjugated linkages of the condensed ring-systems. In the case of the molecular compounds of phenolic bodies colour may be regarded as due to chelation similar to what is obtained in the case of the nitrophenols (Sidgwick and Callow, *J. Chem. Soc.*, 1924, **125,** 533).

The molecular compounds of nitro compounds and halogenated nitro compounds with amines might be said to constitute another structurally different type. It might be noted that the components can be easily recovered from the molecular compounds of nitro compounds and amines, and of tertiary amines with even halogenated nitro compounds (Hepp, *Annalen*, 1882, **215,** 357-358; Sudborough and Hibbert, *J. Chem. Soc.*, 1903, **83,** 1334). But the additive compounds of halogenated nitro compounds and primary and secondary amines are unstable and readily give rise to condensation products (Sudborough and Picton, *loc. cit.*; Buehler, Hisey and Wood, *loc. cit.*, 1911). These are really intermediate products in the course of the reaction between the two molecules and correspond to the second formula of Hertel and Römer :

$$A_1\text{——}M_1\text{——}R_1\text{——}R_2\text{——}M_2\text{——}A_2.$$

Owing to the absence of a reactive group in former class of compounds, the general formula for them may be written thus :

$$M_1\text{——}A_1 \quad : \quad : \quad : \quad R_2\text{——}M_2\text{——}A_2.$$

This would account for the ease with which they can be readily split up into their components.

The characteristic deep colour of the above-mentioned two classes of compounds (Pfeiffer, "Organische Molekülverbindungen," pages 228-229) indicates their structural identity, which is best explained by means of the quinonoid formula of Sudborough and Beard (*J. Chem. Soc.*, 1910, **97**, 780).

ON THE FACTORS GOVERNING THE FORMATION AND THE STABILITY OF COLLOIDAL SOLUTIONS OF SPARINGLY SOLUBLE ORGANIC ACIDS.

BY M. P. VENKATARAMA IYER & H. RAMASWAMY IYENGAR.

(*Department of Chemistry, Central College, Bangalore.*)

The formation and stability of colloidal solutions of substances of a definitely polar character can be explained on the basis of either (*a*) the surface dissociation theory or (*b*) the theory of "adsorption" of ions or other neutral molecules. Achar and Usher in a paper (*J. C. S.* **129**, 1875, 1927) on the production of acidity by neutral salt solutions with stearic acid sols have assumed that the stability of the colloidal solution of stearic acid is due to the adsorption of a non-diffusible ion formed by electrolytic dissociation of the surface of the acid. The part played by methyl alcohol which was employed in the preparation of the sol has been ignored. An attempt has been made in this paper to elucidate the factors which determine the stability of colloidal solutions of sparingly soluble organic acids like stearic, palmitic and oleic acids.

Experiments with stearic acid.—Kahlbaum's stearic acid was recrystallised and used in the following experiments. In order to find out if the presence of a polar group in the solvent employed for the preparation of sol has any effect on the formation and stability of the sol, the following solvents were employed, and the formation or otherwise of the sol was noted. The method of preparation consisted in mixing a solution of stearic acid in the non-aqueous solvent with boiling water, and finally boiling off the non-aqueous solvent with continuous replacement of the water lost by evaporation.

TABLE I.

Solvent Effect.

Solvent employed.	Remarks regarding the formation and stability of sol.	Optimum concentration of sol obtained (gm/litre of stearic acid).
1. Methyl alcohol ..	Very stable and concentrated sol.	2.78 gm./litre.
2. Ethyl alcohol ..	Stable but not so concentrated as 1.	0.84 gm./litre.
3. Propyl alcohol (n) ..	A thin sol.	Very low.
4. Butyl alcohol (n) ..	No sol.	....
5. Formic acid ..	A thick sol but coagulates on standing for 24 hours.	0.26 gm./litre.
6. Acetone ..	A thin stable sol.	Very low.
7. Carbon tetrachloride ..	No sol.	....
8. Ether ..	No sol.	....

Experiments with palmitic acid.—Experiments were also repeated with palmitic acid and it was observed that the general behaviour of this substance was the same as that of stearic acid.

Experiments with oleic acid.—In this case a stable emulsion could be obtained by mixing up a methyl or ethyl alcohol solution with water at ordinary temperature, while in the previous cases (of stearic and palmitic acids), no sol was produced when the mixing took place at room temperature.

Temperature and concentration effect on the formation and stability of stearic acid sols.—The experiments consisted in mixing up drop by drop, stearic acid solutions in methyl alcohol with boiling distilled water of known volume. The resulting sol was boiled to drive off alcohol, care being taken to keep the total volume constant by a slow and continuous stream of distilled water. The sol, when cooled, was filtered through an asbestos filter, and analysed for its stearic acid content. The results are recorded in table II.

TABLE II.

Concentration Effect.

Concentration of alcohol solution.	Vol. of boiling water.	Total final volume.	Concentration of sol in grams per litre.
1. 25 c.c. of saturated solution	200 c.c.	200 c.c.	1.09 gm./litre.
2. ,, +25 c.c. MeOH ..	175 c.c.	200 c.c.	2.78 ,,
3. ,, +50 c.c. ,, ..	150 c.c.	200 c.c.	1.15 ,,
4. ,, +75 c.c. ,, ..	125 c.c.	200 c.c.	1.10 ,,
5. ,, +100 c.c. ,, ..	100 c.c.	200 c.c.	1.01 ,,

There is an optimum concentration of alcohol when the sol of the highest concentration is produced. This behaviour will be considered in the discussion.

Temperature Effect.—Keeping distilled water at different temperatures ranging from the room temperature to 97°C and using methyl alcohol solution of stearic acid of optimum concentration determined from previous experiments, sols were obtained keeping the methyl alcohol-water ratio the same during the process of mixing. The sols were analysed after boiling off alcohol as usual. The results are tabulated below :

TABLE III.

Temperature Effect.

Alcohol-water ratio.	Temperature of mixing.	Concentration of sol.
2 : 7 ..	B. pt. of water (97°C).	2.78 grams per litre.
2 : 7 ..	80°C	2.24 ,, ,,
2 : 7 ..	69°C	2.04 ,, ,,
2 : 7 ..	60°C	0.07 ,, ,,
2 : 7 ..	50°C	0.05 ,, ,,

From the above it will be seen that stable sols are only formed when the temperature of water during the process of mixing exceeds the melting point of stearic acid, *viz.*, 69°C. The higher the temperature the more concentrated and stabler the sol obtained.

Discussion.—From the above experiments there is evidence to show that the presence of a polar group in the solvent employed plays a definite part in determining the stability of the colloidal acid. This is not difficult to understand from the standpoint of the surface orientation theory of Langmuir and Harkins. There cannot be an abrupt transition from the solid phase to the dispersion medium in a stable sol. The only possibility is that the methyl alcohol or any other polar organic solvent employed orients itself between the aqueous and the non-aqueous phases, the hydrocarbon residue pointing towards the solid acid, while the (OH) or other polar group forms a link with water. The formation of an "emulsion" leads to a stable sol, since the transition from one phase to another is more gradual when both the phases are liquids. The forces acting between the molecules of a crystal are well known to be of a much higher magnitude than those in a liquid. This explains the comparative ease with which an emulsion can be formed. The viewpoint advocated here can explain the absence of sol formation when the temperature of mixing is below the melting point of the acid. If formic acid is used as the stabilising agent, though a thick sol is formed due to the orientation effect, coagulation takes place very soon because of the high concentration of H ions derived from the acid. This indicates that though hydrogen ion is a constituent ion of the solid phase, it is not able to stabilise it. This is also shown by cataphoretic measurements with stearic acid sols. The negative charge on the solid phase is diminished to zero value at concentrations of hydrogen ion of the order of pH3, but a higher concentration of the hydrogen ions is not able to bring about a reversal in the charge.

The water-methyl alcohol ratio as a factor determining the optimum concentration of the sol.—It is noticed from table II that neither a too high nor a too low ratio of alcohol-water produces the most concentrated sol. There is an optimum ratio when a sol of the best quality is produced. There are two factors which work in opposite directions in the production of a stable sol. First, a high ratio of methyl alcohol to water brings about a better linking up between the two phases resulting in a stabler sol. Secondly, too high a ratio means a lowering of the dielectric constant and a consequent decrease in stability. This has been verified by the following experiment. If the colloidal solution of stearic acid is mixed with an equal volume of methyl alcohol, partial coagulation takes place.

This shows that methyl alcohol has considerably diminished the stability of the sol by lowering the dielectric constant. Since the two factors indicated above work in opposite directions, there is an optimum methyl alcohol water ratio for the formation of the stablest and most concentrated sol.

From the foregoing we suggest that the non-aqueous solvent employed forms a transition layer between the two phases; the adsorbed water molecules also being responsible for the stability of the colloidal particles. That water molecules play an important part in the stability of the sol is also shown by the following. If aluminium chloride solution is added to the sol in slight excess over what is necessary for coagulation, a stable sol with the electrical charge reversed is obtained. If the same quantity of aluminium chloride is added in instalments so that the sol is first made to coagulate, thus losing its hydration layer, peptisation is not brought about by the excess of the salt added. Since the adsorption of the constituent ion is shown to be rather weak it is necessary to assume that the stability of the colloidal acid is not due to the partial ionisation of the acid so much as to the orientation of the non-aqueous phase at the interface. The charge on the surface of the particles is due to the preferential adsorption of the hydroxyl ions or the anions of the acid. Further evidence regarding the 'adsorption' theory of the stability of these colloidal acids is obtained from potentiometric titrations. This will be dealt with in another paper.

Our best thanks are due to Dr. B. Sanjiva Rao for his kind suggestions.

THE POSTERIOR LYMPH HEARTS OF THE SOUTH INDIAN BATRACHIANS.

PART I.

BY A. NARAYANA RAO, B.SC.

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Some of the earliest papers relating to the anatomy of the Amphibia deal with the structure and physiology of the lymph hearts also. The bulk of this literature refers to Urodeles and European species of Rana, and Beddard (1) has given in his recent contributions a full account of the topographical relationship of the lymph hearts with the surrounding lymph spaces and muscles in four genera of anurous amphibians. The present paper which is based on the results of the investigations of the same subject in some of the South Indian examples sets forth certain facts which have not been, so far as is known to me, hitherto recorded. Ecker (2) describes the posterior lymph hearts of *R. temporaria* "as two lines long and one broad", "the outer surface uneven and appears to be unequally dilated". The two figures given on page 261 in his book (2) and intended to illustrate the relative positions of the anterior and posterior hearts show that they are rounded sacs and the account of these structures by Wiedersheim in his *Comparative Anatomy of Vertebrates* (3) is all too meagre. The lymph hearts of *Breviceps verrucosus* described by Beddard (1) are certainly remarkable structures both for their relative size and open basket-work-like arrangement of the muscles of the organ on the posterior border and the interspaces between the crossing muscle bands open freely into the lymph sac which in the case of this animal is femoral. As the description is based on the naked eye view or the view obtained through a lens, there is no reference to the mechanical contrivance in the lymph hearts of *Breviceps* by which the regurgitation of the lymph into lymph sacs is prevented, which without any valvular arrangement must inevitably occur in view of the extremely large spaces between the muscular intermeshes, which perhaps are in the nature of ostia. As Beddard says, this is really a unique fact in the anatomy of the Batrachians. The point of interest about the lymph heart of *Hemisus* is that it is involved in a mass of fat which occupies the iliac space and the extrinsic muscles of the heart of *Breviceps* are in the case of the former genus represented by connective tissue strands uniting the fat body with the wall of the sac. But in *Xenopus* which has also been investigated by Beddard, there is a variable number of hearts on each side of the urostyle and the largest number is three pairs which are detached and separate. Beddard concludes that this multiplicity must be related to the disproportionately large pair of hind limbs and the relatively feeble fore-limbs (the anterior lymph hearts being always a single pair), since the lymph hearts are connected with veins supplying the fore and hind limbs. This suggestion of the retention of plurality of lymph hearts would be certainly significant if their number were not variable on each side in the same individual and from individual to individual, sometimes the number on any one side is reduced to one. He next proceeds to account for this large number in cases where they are found, by suggesting that they are "derivatives of the chain of lymph hearts in certain Urodeles". Further the lymph hearts of *Xenopus* are not all of a uniform size. I shall soon revert to this really interesting discovery of the multiple lymph hearts in anurous forms whose habits are thoroughly aquatic.

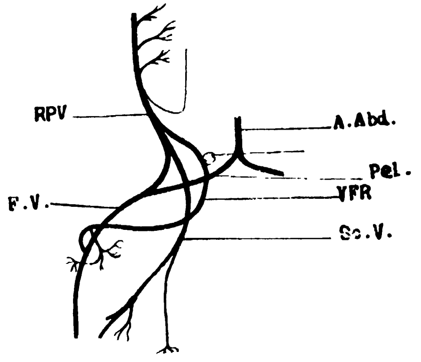

Fig. 1.

Cacopus systom :.—Posterior lymph hearts placed on *Vena femora renoportalis* which arises from the femoral and opens into the renoportal vein.

I am dealing in this paper which forms the first part of my studies, with certain frogs whose modes of life are sharply demarcated. *Rana hexadactyla* and *R. cyanophlyctis* are totally aquatic; *Cacopus systoma* and *Bufo melanostictus* are purely terrestrial forms while *Rana tigrina* is semi-aquatic. Some of these attain great proportions and their hind limbs as in *Rana hexadactyla* and *Rana tigrina* attain quite an enormous dimension.

If the number of posterior lymph hearts is to some extent determined, as has been suggested by Beddard, by the size of the hind limbs, then the suggestion may be found exemplified in these two frogs. Or if the size, number and topographical relationships of the lymph hearts have anything to do with the diversity of life habits assumed by the members of *Batrachia salientia,* then the frogs I have selected for study may be deemed fairly typical for purposes of arriving at some tentative conclusions.

In the forms I have investigated, the posterior lymph hearts are placed on either side of the urostyle near its end and covered only by aponeurosis and the skin. Each sac lies in and is surrounded by lymph spaces. The walls consist of muscle fibres arranged in a plexiform manner and supported by a considerable amount of connective tissue. These fibres are striated and branched and are intermediate between the cardiac and skeletal muscle fibres. The muscular wall is supplied with capillary blood vessels. The interior is lined by epithelioid plates of sinuous outline. This lining is continued along a number of openings by which the cavity opens into the surrounding spaces.

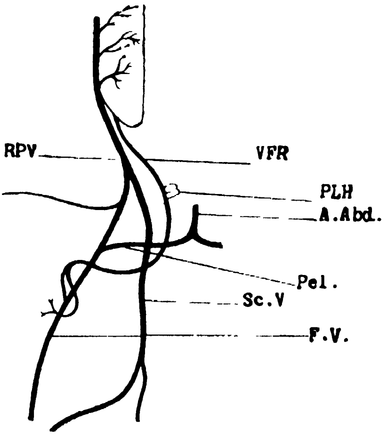

Fig. 2.

Cacopus systoma.—Posterior lymph hearts placed on *Vena femora renoportalis* which opens directly into the kidney.

The peculiarly fat habit of *Cacopus systoma* is due to the inclusion of the thighs within the contour of the body, which extends some distance behind the tip of the urostyle. The posterior lymph hearts lie in the spaces on either side of the urostyle and these spaces, possibly corresponding to the iliac sacs of Ranidæ, are in free communication with the femoral lymph sac behind and anteriorly with the dorsal and lateral lymph sacs. The septal membranes between the larger lymph sacs in the trunk are well developed except where free communications with the iliac sac exist. These communications are the enlarged ostia which occur in larger numbers in the Ranid forms. Each heart (Plate I) is roughly conical with the apex directed posteriorly. It receives an arterial branch from the iliac. The internal cavity is irregular in outline and the heart opens into a vein springing from the femoral at a point well behind that from which it divides into the pelvic and renoportal. This vessel is quite as stout as the sciatic or the femoral itself and anteriorly it joins the renoportal before it enters the kidneys or joins the kidneys directly. Manifestly this vessel corresponds to the vena iliaco communicans referred to by Holmes (4), but it has nothing to do with the sciatic. Externally two slight grooves divide the heart into three parts, which do not, however, affect the cavity. There are two ostia posteriorly and one in front which are provided with valves and the opening into the blood vessel is similarly guarded. The extraordinary thickness of the wall is a striking feature. The anterior heart, which occupies the usual position described in the case of Rana, shows a canaliculated wall, the canals opening into the central chamber at different levels. It opens into the subclavian vein. The anterior and the posterior lymph hearts are of the same size and in a specimen measuring about 59 mm. the heart is 3·5 mm. But this small size of the heart is more than compensated for by the development of secondary lymph sacs in the neighbourhood, apparently representing detached portions of the main lymph spaces.

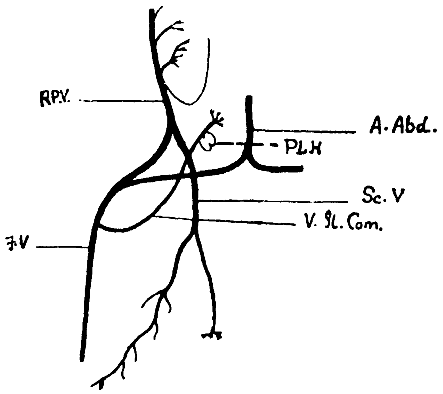

Fig. 3.

Rana cyanophlyctis.—Posterior lymph hearts are placed on a vessel which arises from the loose pigmented tissue near the iliac sac and opens into the femoral vein.

In the cases of *Rana hexadactyla* and *Rana cyanophlyctis*, the posterior lymph hearts present a tendency towards multiplicity. In the former species, they are bilobed (Plate 2) and in the latter case trilobed (Plate 3). The lobes are distinct separated by deep constrictions. Here we have a parallel to the condition met with in *Xenopus* which is purely an aquatic form. The position of these multiple hearts which are uniform in their occurrence is the iliac lymph space and in *Rana hexadactyla* the two lobes are placed side by side, one internal and the other external; of these the outer lobe is larger. In *Rana cyanophlyctis* the lobes are obliquely placed. They are not in both cases related to the vena iliaco communicans; but are placed on a vein arising from the loose pigmented tissue in the neighbourhood and opening into the femoral in the case of *Rana cyanophlyctis* and into the sciatic in *Rana hexadactyla*. The trilobed heart of *Rana cyanophlyctis* is wrapped up in an external coat of muscle probably corresponding to the adductors described by Beddard in *Breviceps*. All the lobes are separated from one another by thick muscular septum which might give rise to secondary spaces opening by a valvular aperture into the hindermost lobe. The iliac arterial branch enters between the anterior and the middle lobe in *Rana cyanophlyctis* and all the lobes have separate openings into the vein. Behind the last lobe there is a small lymph space, the chamber of which is divided into a number of secondary spherical cavities, perhaps acting as an additional absorptive organ. In *Rana hexadactyla* the two hearts are discrete and are not wrapped up in any muscular sheath. In both these examples the lymph spaces are comparatively smaller than in *Cacopus systoma*.

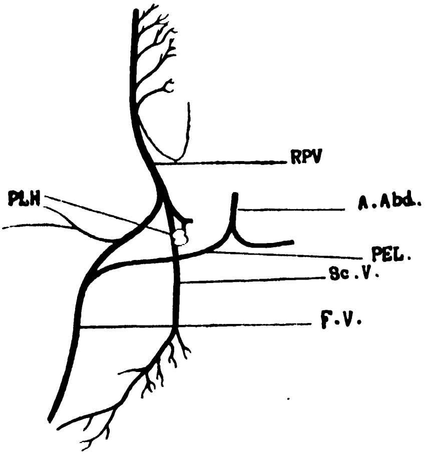

Fig. 4.

Rana hexadactyla.—The venous connection of the lymph heart arises as in *Rana cyanophlyctis* but opens into the sciatic vein. Connection with the femoral is lost.

In *Bufo melanostictus* the lymph heart (Plate 4) is an oval body, the posterior margin presents the basket work noticed and described by Beddard in *Breviceps*. It is comparatively smaller than in *Breviceps* and *Cacopus*. A portion of the wall of the heart taken from the hinder end, stained in eosin and mounted, presents a trellis work the intermeshes being irregular in outline. Another feature which I have not noticed in the other frogs is the presence of two lymphatics connected with the anterior and posterior ends of the heart. The anterior one comes from the dorsal lymph sac and the posterior from the ventral lymph sac. These tubes open by valvular apertures into the heart, bringing lymph from the two large sacs. The iliac lymph space is directly drained by the fenestrated margin of the lymph heart.

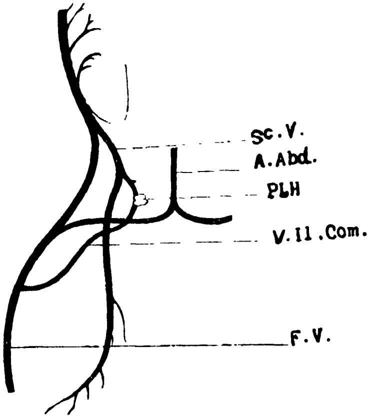

Fig. 5.

Rana hexadactyla.—Posterior lymph hearts are placed on a vessel connecting the femoral and sciatic veins. The condition is described for *Rana pipiens* by Holmes.

There are two outstanding facts in the study of the posterior lymph hearts of the four examples which I have selected for description in this communication. The relation of the heart to the veins presents, in the first place, certain variations which have not been noticed before. In the second place, the multiplicity of the hearts in aquatic forms is more pronounced than those which have assumed a terrestrial mode of life. Taking the former feature first, I notice that in *Cacopus* and *Bufo*, the venous connection of the posterior lymph heart is with a vessel which arising from the femoral joins either the renoportal (Text Fig. 1) or the kidney directly (Text Fig. 2). In ***Rana cyanophlyctis*** the veinlets arising from the loose pigmented tissue in the neighbourhood of the iliac sac form a thick vein which ultimately opens into the femoral vein (Text Fig. 3). Into this vein the heart opens. But in ***Rana hexadactyla*** the same vein arising similarly and on which the posterior lymph hearts are situate, opens into the sciatic (Text Fig. 4). According to Holmes who has given a description of ***Rana pipiens*** in his ***Biology of the Frog***, the posterior lymph heart opens into the transverse iliac vein (Text Fig. 5). This is in conformity with the description of *Rana esculenta* given by Ecker. ("The posterior lymph hearts receive lymph from the parts surrounding them and from the hinder extremities and forward it into the vein—vena iliaco communicans"—the transverse iliac vein of Holmes.) But according to Marshall (5) the hearts in *Rana temporaria* "communicate by short vessels with the femoral veins" (Marshall's *Frog*, p. 37). Manifestly *Rana temporaria* differs from *Rana pipiens* and *Rana esculenta* and in a measure conforms to the South Indian *Rana*. The difference, however though a matter of detail, is that the vein on which the heart is situated in the South Indian examples opens into the femoral or sciatic directly without breaking into smaller veins as in the case of *Rana temporaria*. There can be very little doubt that this vein corresponds to the vena iliaco communicans of Ecker, with this difference that it has lost communication with the sciatic in *Rana cyanophlyctis* and with the femoral in *Rana hexadactyla*. In *Cacopus systoma* and *Bufo melanostictus* the vein into which the heart opens, arising from the femoral, opens into the renoportal or into the kidney and must be homologous with the vena iliaco communicans, for the connection has in these two cases shifted forward to the extent of coming into direct contact with the kidney or the renoportal before it debouches into the kidney. If, however, strict terminology of veins in this region requires that the vena iliaco communicans should be confined to the transverse vessel connecting the sciatic and the femoral in the groin, then the vessel into which the lymph heart of *Cacopus* and *Bufo* opens must be named differently as its relation is not with the femoral and the sciatic, but with the femoral and the kidney or with the renoportal. This is not a new vessel but only a modified transverse iliac vein, and in that case the definition of the latter ought to embrace a reference to its relation with the renoportal and where it joins the kidney separately, it must be assumed that the extreme point to which modification can go, has been reached. For purpose of descriptive zoology this vessel may be named *Vena Femora Renoportalis*.

The second interesting feature in the organisation of the lymph hearts is their multiplicity in thoroughly aquatic forms; this character shading off as we pass from the aquatic to thoroughly terrestrial forms. As Beddard points out their chief interest centres in the possibility of comparing them with the multiple lymph hearts of certain Urodeles. He quotes the following from Wiedersheim's *Vergleichende Anatomie der Werbelthiere* : " Beo Salamandra maculosa und Siredon pisciformis sitzen zahlreiche Lympherzen langs des Sulcus lateralis unter der Haut und zwar entfallen bei dem erstgenannten Their auf dem Schwanz (beide Seiten zusammengerechnet) 10-12, auf den Rumpf mindestens ebensoviel. Bei Siredon pisciformisfinden sich jederseits 8 rhythmisch pulsirende Bympherzen die wie beo Salamandra maculosa aus ovalen, von quergestreifter Muskulatur umwickelten Blaschen bestehen." Wiedersheim is here dealing with spotted Salamander, which, though a terrestrial form, is, according to Gadow, fond of moisture in the moss, springs and running water and with Axolotl larva which is purely aquatic, though the adult Ampblystoma is terrestrial. Generally speaking, in Urodeles (Wiedersheim and Parker) " there are as many as 11-20 lymph hearts on either side of the trunk and tail under the skin at the junction of the dorsal and ventral trunk muscles," and though some examples have left the water, still in consequence of their repeated visits to that element, the reduction in the number of hearts has not taken place to the extent that one might expect. In the group Ecaudata the suppression of the tail synchronises, as is evidenced in ontogenetic development, with the assumption of terrestrial life and this profound change affects more than one system of the soft anatomy. When the circulatory system undergoes a radical change it must involve the lymphatic system also. We can therefore easily account for the reduction in Anura of the lymph hearts to an anterior and posterior pair which must have formed in their larvæ one continuous chain as in Urodeles.

ABBREVIATIONS.

A.Abd.	..	Anterior abdominal vein.
F.V.	..	Femoral vein.
Pel.	..	Pelvic vein.
PLH.	..	Posterior lymph heart.
RPV.	..	Renoportal vein.
Sc.V.	..	Sciatic vein.
VFR.	..	Vena femora renoportalis.
V. Il. Com.	..	Vena iliaco communicans.

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3. Wiedersheim .. "Comparative Anatomy of Vertebrates."
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5. Marshall .. "The Frog."
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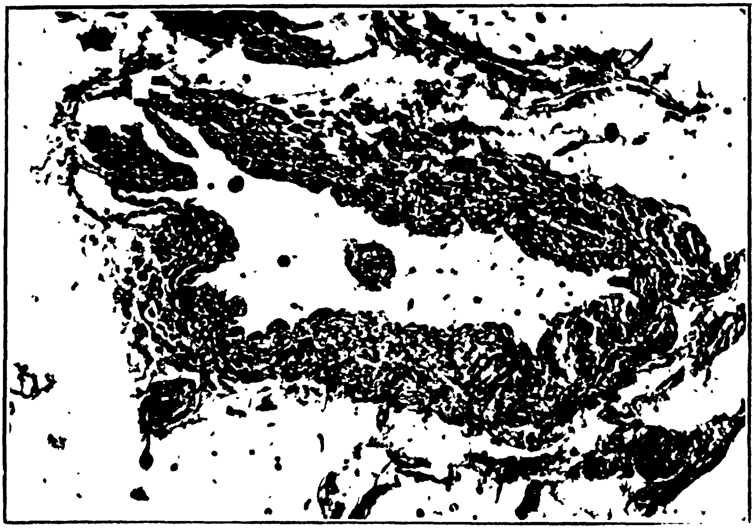

Plate 1.

Photomicrograph of the longitudinal section of the posterior lymph heart of *Cacopus systoma.*

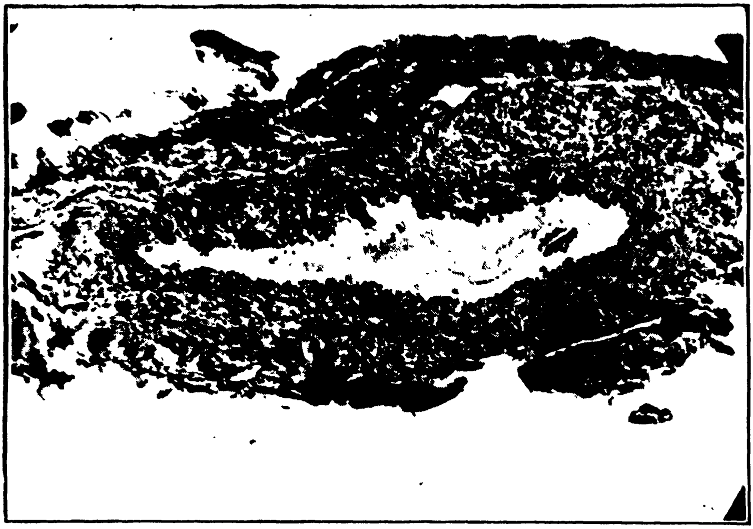

Plate 2.

Photomicrograph of the longitudinal section of the posterior lymph heart of the toad *Bufo melanostictus.*

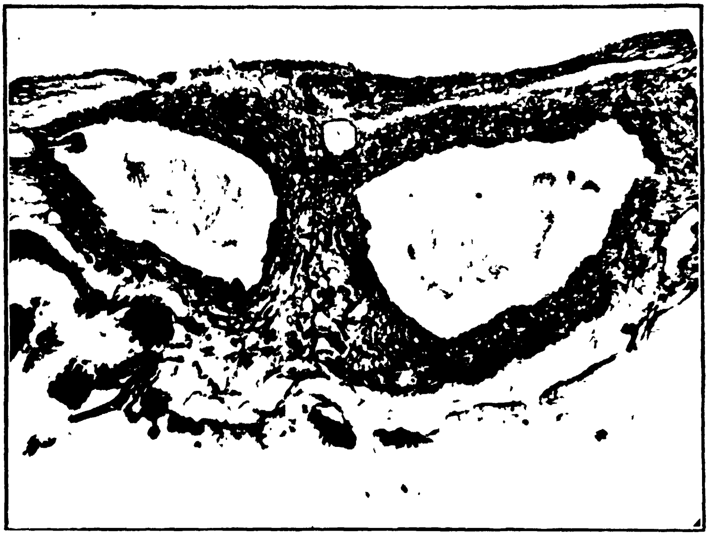

Plate 3.

Photomicrograph of the transverse section of the posterior lymph heart of *Rana hexadactyla.*

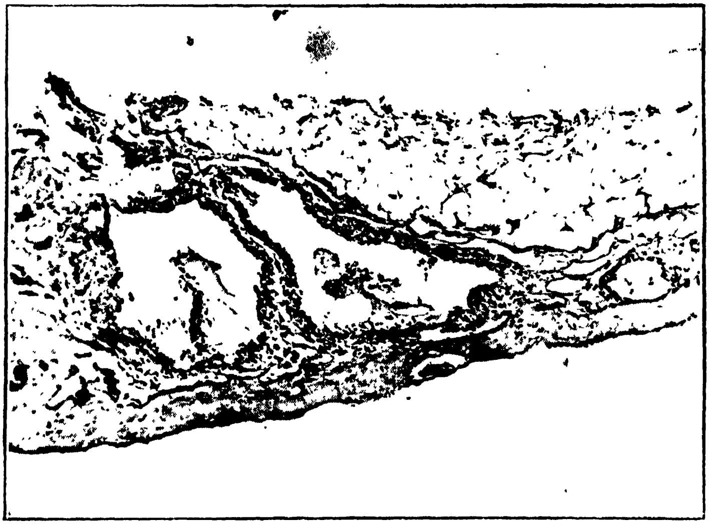

Plate 4.

Photomicrograph of the longitudinal section of the posterior lymph hearts of *Rana cyanophlyctis.*

THE STRUCTURE OF THE HYOID APPARATUS AND LARYNX IN THE SOUTH INDIAN *ENGYSTOMATIDÆ* (ANURA).

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(Text-figures 17.)

The study of the Anuran hyoid apparatus and larynx has been engaging the attention of scientific workers from early times (11, 15) and none of these authors has referred to the disposition and structure of the larynx in the group Engystomatidæ, except, however, Miss Mary Frazier who makes a brief reference to a single example *Microhyla okinavensis* (1). It may at once be stated that the larynges of the South Indian Engystomatid forms differ fundamentally on the one hand from the common Ranid type and on the other from that of the Engystomatid that has been described by Miss Frazier (1). The latest contribution to our knowledge of this subject is an exhaustive account by W. Blume (2) and he does not refer to the earlier author, Miss Frazier. The object of this paper is to describe the hyoid apparatus and the larynx of the three narrow-mouthed toads *Cacopus*, *Kaloula* and *Microhyla*. *Cacopus* is practically confined to South India; *Kaloula* and *Microhyla* are a little more cosmopolitan in distribution. I have also made a comparative study of the larynges in both sexes of the other South Indian frogs such as:—

Bufo.
Nannobatrachus.
Nyctibatrachus.
Ixalus.
Micrixalus.
Rhacophorus maculatus.
Rana hexadactyla.
R. curtipes.
R. crassa.
R. breviceps.
R. tigrina.
R. cyanophlyctis.
R. malabarica.
R. beddomii.

In this connexion, I wish to express my sincere thanks to Professor C. R. Narayan Rao for having kindly directed me in this work.

The Hyoid Apparatus.

The hyoid apparatus in *Cacopus* has been described by Devanesan (3). In the allied South African Engystomatid forms the hyoid has been described by de Villiers (4, 5) and in describing the cranial osteology of *Cacosternum* (5), de Villiers remarks that the hyoid of this form is typically Ranid. The apparatus in *Breviceps* (6) does not resemble that in *Phrynomerus* (4). Thus, if *Phrynomerus* be taken as a typical South African Brevicipitid Engystomatid frog, then a close homology could be established between the South Indian and South African forms.

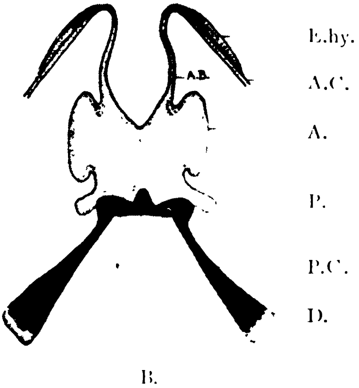

Fig. 1.

The entire hyoid-apparatus of Kaloula.

Though the hyoid of *Cacopus* resembles the apparatus in *Kaloula* and *Microhyla*, there are two important points of difference. The possession of the extrahyal, anterior and posterior cartilaginous processes of the basihyal and the cartilaginous anterior and the bony posterior cornu are common to all the three forms. In *Kaloula* and *Microhyla* a definite cartilaginous diapophysis at the ends of the posterior cornu is noticed; this is not figured by Devanesan (3) for *Cacopus* nor by de Villiers (4) for *Phrynomerus*. Further in *Kaloula* and *Microhyla* the proximal ends of the posterior cornu are not separated by a cartilaginous

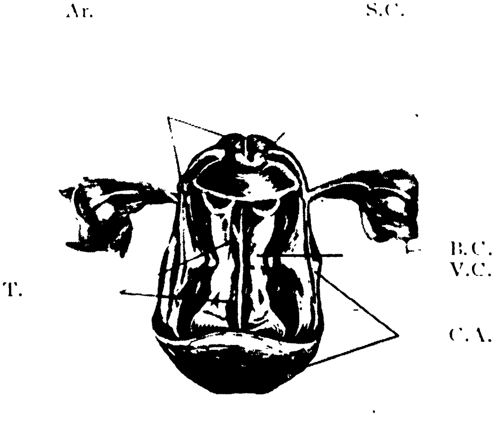

Fig. 2.

The entire larynx of Cacopus.

bridge as seen in *Microhyla* and *Cacopus*; there is a beak-like bony projection (see text Fig. 1) which bridges the gap between the two thyroid processes. Miss Frazier in describing the Chinese form *Microhyla okinavensis* does not allude to the presence of a small extra-hyal attached to the anterior bend of the anterior cornu, nor does she refer to the median beak-like cartilage or bone in connexion with the thyroid processes.

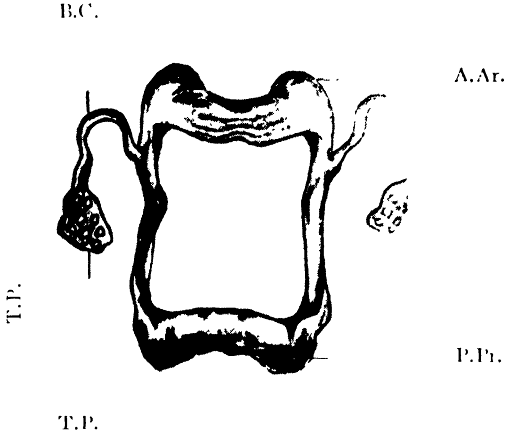

Fig. 3.

Photograph of the drawing of the entire cricoid annulus of Cacopus.

The Larynx.

The laryngeal structures of these narrow-mouthed toads present certain features which have not been noticed by any previous workers in the examples investigated by them. The vocal organ is situated between the thyro-hyals, in close contact anteriorly with the basi-hyal. The cricoid forms a close ventral ring for the two halves of the arytenoids (see text Fig. 2). The arytenoids are completely surrounded by the ring-like cricoid piece, unlike the Ranids and the examples of Bufo that I have examined. Both in front and behind the cricoid annulus expands into fairly large cups which are firmly attached to the arytenoids and extend over the anterior and posterior divisions of the laryngo-tracheal chamber in a manner unusual in the other South Indian batrachians which I have investigated. W. Blume (2) gives

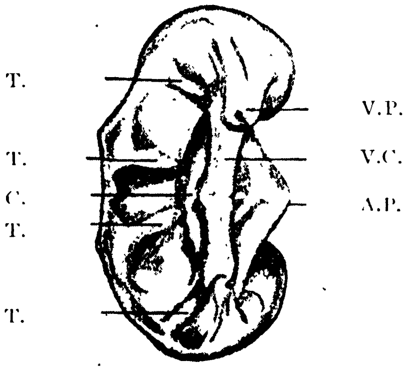

Fig. 4.

Single arytenoid cartilage of Cacopus. (Internal aspect.)

a figure of the laryngeal apparatus of a Ranid (page 312) where he marks two cup-like prominences on the cricoid annulus. He has labelled them following Gaupp the processus articulares anteriores and posteriores but they are situated not at the ends of the annulus. These cups are not so prominent in *Kaloula* and *Microhyla* as in *Cacopus*. These expansions may, therefore, be called respectively the processus articulares anteriores and posteriores (see text Fig. 3). Another characteristic feature of the cricoid is that in all the three forms it does not bear the pharyngeal or oesophageal process (*spina oesophagea* Gaupp) so common among the other Anura and it is common to both sexes. However, I must point out here, that in the case of male examples of all the forms I have examined other than the Engystomatidæ, this oesophageal process is wanting while it forms a conspicuous rod-like cartilage in the female specimens of the same species. Thus, the sex of these forms could be easily correlated with

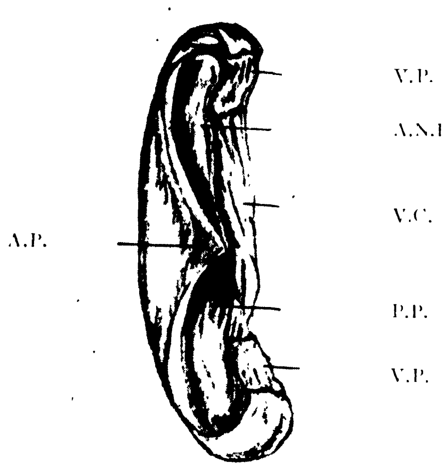

Fig. 5.

Photograph of the drawing of the ventral view of the arytenoid cartilage.

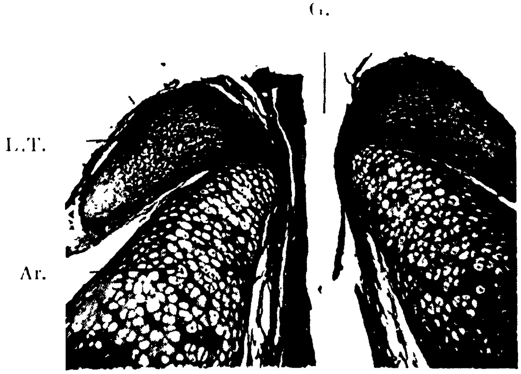

Fig. 6.

Photomicrograph of the transverse section of the dorsal part of the larynx of Cacopus.

the presence or absence of the oesophageal process. Extending posteromedially and usually bent inwards are two broncheal processes (*processus trachealis* Gaupp) which serve to hold the roots of the lungs to the larynx. The distal extremities of these processes are usually expanded into squarish perforated areas and when they meet over the roots of the lung ventrally, constitute a tracheal ring. The other process termed the anterior pharyngeal processus (*processus muscularis* Gaupp) is absent from all the three toads.

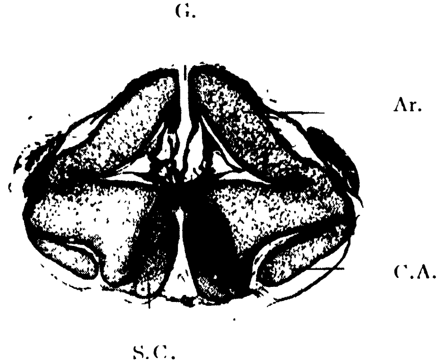

Fig. 7.

Photomicrograph of the transverse section of the larynx of Cacopus. (Anterior end.)

The arytenoids which are broadly triangular like the shell of the fresh water mussel are paired and lie parallel to the long axis of the hyoid apparatus (see text Figs. 4 & 5). Each cartilage is thick and like the shell of Unio, has the concave surface directed inwards (cardiac aspect). The glottis is a long median slit extending from one end of the apparatus to the other over the apex of the arytenoids which is thus dorsal and pharyngeal in position. Extending from the dorsal margin of the arytenoid cartilage in all the three examples is seen for a short distance a club-shaped cartilage (see text Figs. 13 & 15) and further the arytenoid cartilage is covered over by a well-developed loose tissue (see text Fig. 6) in *Cacopus* and *Kaloula*. This tissue while it

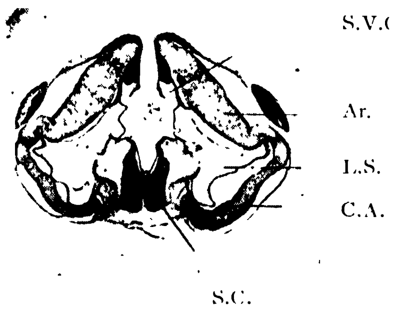

Fig. 8.

Photomicrograph of the transverse section of the larynx of Cacopus, posterior to Fig. 7.

forms a cap for the dorsal extension of the arytenoid cartilage in *Cacopus*, remains a discrete element in *Kaloula*. What exactly the function of this tissue is, it is difficult to say. Moreover, there is a longitudinal slit running along the middle of the arytenoid cartilage in all the three examples. In this particular character the South Indian forms resemble *M. okinavensis* (see text Fig. 13).

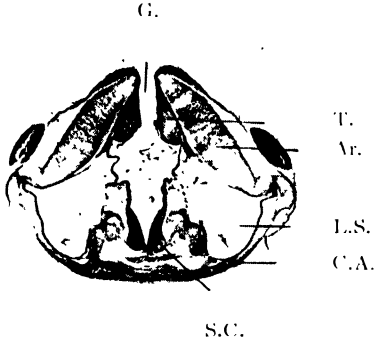

Fig. 9.
Photomicrograph of the transverse section of the larynx of Cacopus, posterior to Fig. 8.

I may state at once that the cartilage of Santorini (*cartilago apicalis* Gaupp) usually stated to occur in the form of a microscopic cartilaginous nodule in the middle of the arytenoid apex is absent from all the three forms. In *Cacopus* on the inner margin of each arytenoid just above the vocal cords is a series of four fairly conspicuous conical processes (see text Fig. 16). This is a feature which I have not noticed in the larynx of *Kaloula* or *Microhyla* or any other form that I have examined. The histology of these tooth-like structures is interesting; they present bundles of compact connective tissue studded with nuclei. The two median ones are free from any attachment while the terminal ones give attachment to the proximal parts of the vocal cords. On the cardiac aspect, the arytenoids are enclosed by broad hood-like expansions of the cricoid as already said.

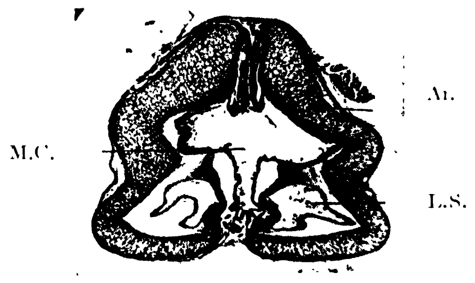

Fig. 10.
Photomicrograph of the transverse section of the larynx of Kaloula. (Anterior end.)

There are a few more singular features in the anatomy of the larynx of these forms to which I now proceed to refer. The inner margin of the vocal cords is not straight and in cross sections presents an irregular outline. The tracheal chambers on each side enclosed by the cricoid annulus and the vocal cords are deep and divided into anterior and posterior sections which are separated from each other by a vertical membranous fold extending from the beak-like process of the arytenoid to the vocal cords (see text Fig. 5). In the cross sections of the larynx the dorsal extensions of the tracheal chambers appear as two lateral sinuses discrete from the median glottis.

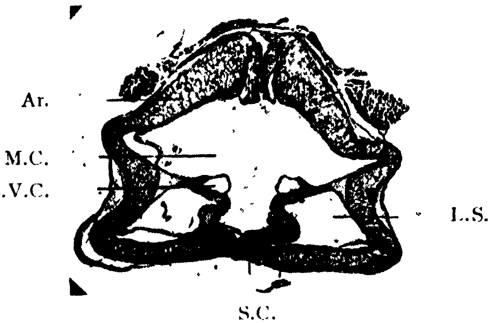

Fig. 11.
Photomicrograph of the larynx of Kaloula, posterior to Fig 10.

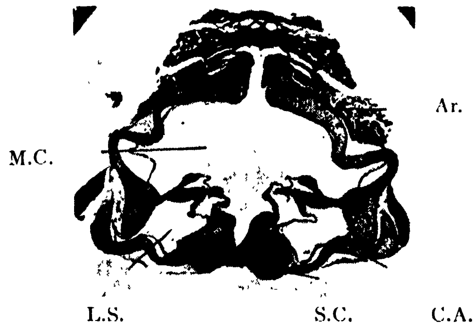

Fig. 12.
Photomicrograph of the transverse seciton of the larynx of Kaloula, posterior to Fig. 11.

The principal laryngeal muscles which can be dissected from the ventral aspect of a frog like *Rana hexadactyla* or *Rana tigrina* are the dilator and constrictor laryngis, the hyoarytenoideus anterior and posterior and finally a slip of muscle petrohyoideus tertius extending across the cardiac margin of the arytenoids. These muscles arise from the pharyngeal margin of the cricoid and run vertically dorsally about halfway of their course and then taking a posterior direction, become inserted into the dorsal muscles (muscle latissimus dorsi) (see text Fig. 17). I may mention here that Miss Frazier (1) who has described the structure of the larynx of the Chinese species of *Microhyla*, does not allude to the presence of such muscles; in fact she does not describe the laryngeal muscles at all. The contraction of these muscles must have the effect of swinging out the pharyngeal cup of the cricoid and thus widen the dorsal tracheal chambers. The cardiac portion of the cricoid which is also cup-like in these forms is held in position by the connective tissue attachments with the basihyal. These muscles (muscle protractor cricoideus), therefore, are protractors.

DISCUSSION AND SUMMARY.

It is obvious from the study of the laryngeal apparatus of these narrow-mouthed toads that we could establish two groups,—the *Cacopus* group and the *Kaloula-Microhyla* group. A similar grouping with reference to the disposition of the valves in the heart and the structure of the heart, has been noted by Professor C. R. Narayan Rao (17). It must be mentioned, however, that there is not a definite line of demarcation between the two groups so formed.

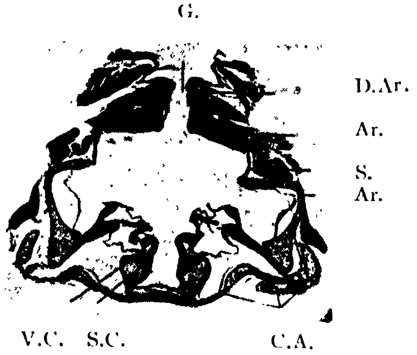

Fig. 13.

Photomicrograph of the transverse section of the larynx of Kaloula, slightly posterior to Fig. 12.

The points in common between the two groups may be mentioned. The larynges of the male forms are larger than those of the females. This is a matter of common observation and it is noticed even in cases where the male does not possess enormous croaking powers. It must be mentioned here that the vocal sac of the male *Cacopus* is an extraordinarily wide pouch and when fully distended is oval in outline and is nearly half in the total length of the animal.

Some of the anatomical peculiarities of the larynx must be correlated with the powerful voice with which nature has endowed this creature. During the greater part of the year *Cacopus* lies buried deep in the ground and comes out after heavy rains. The cry of this toad has been usually compared with the bleating of goats (7) but I doubt the accuracy of this description. It is a well-known fact that the large vocal sac by being puffed with air helps to intensify the sounds arising in the vocal organs and the surface of the water on which the vocal sac reposes very considerably increases the intensity of the sound acting as a resonator. *Microhyla* and *Kaloula* do not possess a vocal sac.

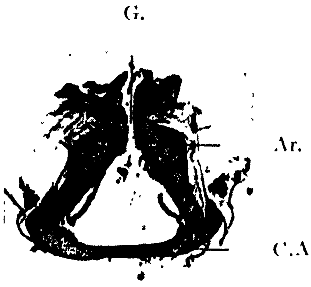

Fig. 14.

Photomicrograph of the transverse section of the larynx of Microhyla. (Anterior end.)

The complete inclusion of the arytenoids within the cricoid annulus is a non-ranid feature; further the absence of the processus muscularis and the spina oesophagea are specific characters of the South Indian Engystomatidæ. The presence of the spina in the Chinese form has already been noted. It was remarked that the presence or absence of the spina oesophagea in the Ranids was so closely correlated with the sex of the individual that it was made a sex determiner. Great emphasis cannot be laid on this point, for in two specimens of *Rana tigrina* and *Rana breviceps* I have noticed the presence of the oesophageal process even in the male. Thus this criterion cannot be very safely relied upon.

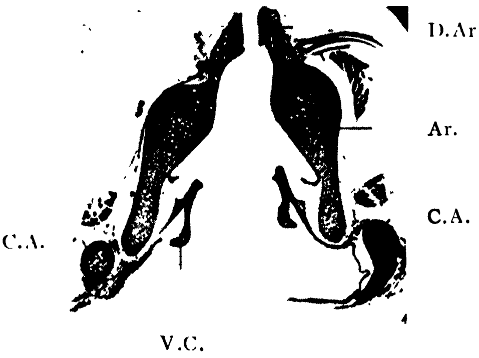

Fig. 15.

Photomicrograph of the transverse section of the larynx of Microhyla, posterior to Fig. 14.

The two cup-like expansions in the oesophageal end of the cricoid have been compared with the articulares anteriores and the posterior ones near the cardiac end to the articulares posteriores; this process—processe articulares or the articular process—is a definite projection on the annulus in *M. okinavensis*.

The distal expansions of the broncheal processes forming a ring over the proximal ends of the lungs deserve mention. Such expanded cartilages are noticed in the case of Urodela. Thus the anuran cartilage may be homologised with the tracheal cartilages of the Urodela. Further, these two broncheal cartilages do not fuse in the middle line to form, as in *Rana esculenta*, process pulmonales and process obturatorius (Gaupp).

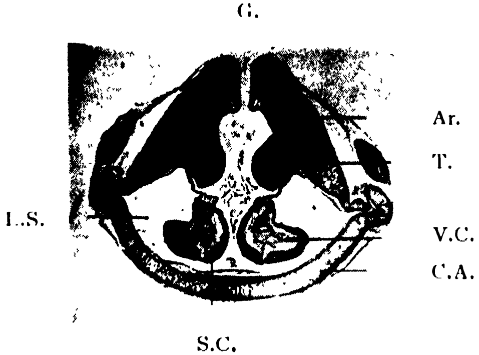

Fig. 16.

Photomicrograph of the transverse section of the larynx of Cacopus, in the anterior region.

At the region marked X the two lateral sinuses become one with the median chamber, and open into the pharynx by the glottis (G).

The cartilago apicalis is absent from all the three forms. The slit in the arytenoid cartilage has already been mentioned. *Cacopus* stands apart from the other two examples in the possession of the teeth on the internal surface of the arytenoids ; the distal two further attach the vocal cords to the arytenoids. In all the three forms, at the points of attachment of the vocal cords with the arytenoids there is a cartilaginous support. The two vocal cords thus arising from the thick pillars is further attached with the arytenoids in their centre to the beak-like process already referred to. This beak-like process is poorly developed in *Microhyla* and *Kaloula*.

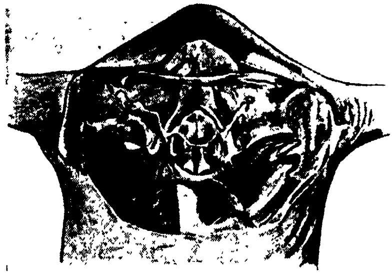

Fig. 17.

Photograph of the drawing of the larynx *in situ* of Cacopus, showing the new muscle (x) and vocal sac.

Howes (8) describes in the case of *Leptodactylus* and *Rana pipiens*, a couple of folds uniting to form a lip on the hind boundary of the glottis, with another fold, the epiglottis, on the other side of the auditus. This lip-like fold he calls the 'epilaryngeal fold'. Both these folds, the epiglottis (membranous in those anura possessing it and homologised with the chondrified ones in the mammals) and the epilaryngeal, are absent from the three genera under discussion.

The hyoid apparatus in all the three examples is based on a common plan. Only the thyroid processes differ. In *Cacopus* there is a cartilaginous bridge between the two bony processes; in *Microhyla* there is a cartilaginous beak-like portion connecting the two, and in *Kaloula* this beak-like portion is bony. The anterior body process of the basihyal is very short in *Cacopus*, while in *Kaloula* and *Microhyla* they are long. An extra-hyal common to all the three South Indian Engystomatidæ is wanting in the Chinese form. The hyoid apparatus of the South African forms resemble more *Microhyla okinavensis* than the South Indian forms.

The muscle protractor cricoideus is common to all the three forms.

The variations in the laryngeal structures of these forms could only be properly elucidated provided the developmental history of these forms is well known. This problem is engaging the attention of the writer.

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ABBREVIATIONS.

A.	Anterior process of the basi-hyal.
Ar.	Arytenoid.
A.Ar.	Anterior articular process.
A.B.	Anterior body process.
A.C.	Anterior Cornu.
A.N.P.	Anterior chamber.
A.P.	The median process from the arytenoid cartilage.
B.	Bony beak-like process.
B.C.	Broncheal process.
C.	Cavity in the arytenoid.
C.A.	Cricoid Annulus.
D.	Cartilaginous diapophysis.
D.Ar.	Dorsal extension of arytenoid cartilage.
E.hy.	Extra-hyal.
G.	Glottis.
L.S.	Lateral sinus.
L.T.	Loose tissue capping the arytenoid cartilage.
M.C.	Median chamber.
P.	Posterior process of the basi-hyal.
P.C.	Posterior Cornu.
P.P.	Posterior chamber.
P.Pr.	Posterior articular process.
S.	Slit in the arytenoid.
S.C.	Cartilage support of the vocal cord.
S.V.C.	Space in the vocal cord.
T.	"Teeth".
T.P.	Terminal expansion of the broncheal process.
V.C.	Vocal cord.
V.P.	Pillar for the attachment of the vocal cord (V.C.).

THE CRANIAL OSTEOLOGY OF THE SOUTH INDIAN *ENGYSTOMATIDÆ* (ANURA).

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INTRODUCTION.

In a preliminary communication to the *Current Science* (1) it was reported that in order to establish the systematic position of the group Engystomatidæ (Anura) all the organs were being studied from a developmental standpoint. It is necessary, however, in order to facilitate the discussion of the relationships of the three genera, *Cacopus*, *Kaloula* and *Microhyla*, a correct conception of the structural details of the head must be made known. In order to make a comparative study of these characters, heads of these genera were decalcified and sectioned; besides, the metamorphosing tadpoles were also sectioned and studied. Alizarin preparations of the entire animals were also made for studying the gross outlines of the bones.

In this connexion I must express my debt of gratitude to Professor C. R. Narayan Rao, M.A., whose constant encouragement and direction have enabled me to finish this piece of work. I must also thank Miss T. P. Vanajakshi, B.Sc., for making the alizarin preparations of the frogs.

MATERIAL AND METHOD.

The metamorphosing tadpoles of *Cacopus* and *Microhyla* collected during the rains of July and August, were fixed in Bouin's fluid. The early stages of *Kaloula* I was not able to secure. The heads of the adults of all these three genera were fixed in Bouin and later decalcified in the oft-used fluid—70 per cent alcohol containing 1 per cent nitric acid. Jenkin's fluid which does not entail a previous fixation was also tried. Both these fluids have given very good results. Sections ten microns thick were cut and stained in hæmatoxylin—eosin, aqueous fuchsin and also triple stains like hæmatoxylin—picroindigocarmine, Pasini and Mallory.

The Nasal Capsule.—The complicate nature of the olfactory capsule in *Rana fusca* has been described in detail by Gaupp (2). The latest work bearing on this subject is by de Villiers who has described the South African forms like *Arthroleptella* (3), *Hemisus* (4), *Breviceps* (5), *Phrynomerus* (6) and *Cacosternum* (7).

Cacopus possesses both the prenasal cartilages (the prenasalis superior and prenasalis inferior) and in this respect it resembles more the Ranid form and also the South African forms like *Phrynomerus*, *Cacosternum* and *Breviceps*. In *Microhyla* and *Kaloula* only the superior cartilage is present. This is a long and thick cartilage and is the main support for the premaxilla. The internal terminal part of this prenasal cartilage is located just at the point the cartilago alaris takes its origin from the septum nasi. In *Cacopus*, however, the superior is flexed beneath the septum nasi. The cartilago alaris and cartilago obliqua are both present. The cartilago alaris. a thick and cup-shaped cartilage in *Kaloula* and *Microhyla*, while being less arched in *Cacopus*, takes its origin from septum nasi and gives attachment to the superior nasal cartilages. The three chambers, the cavum principale, cavum medium and cavum inferius, are present. According to Bruner (8) the lateral vestibule of cavum superius- (also described by Born) is separated from cavum superius itself by folds only ; and the fold connected with the posterior wall of the vestibule attains enormous size. This fold called by Bruner the plica obliqua is attached in *Rana* to the cartilaginous roof of the nasal capsule. However, in all the three genera, like the South African forms, the plica depends from the cartilago obliqua and not from the cartilaginous roof of the nasal capsule. There is a definite dent in the septum nasi dorsally in *Kaloula* and *Microhyla* while it is flat in *Cacopus*. Further, a slight ossification of the septum nasi could be seen in *Cacopus*. No sooner the external nares closes up, the cartilago alaris also disappears and the place is taken up by a thin Gauppian Wulst. The vestibule is fairly moderate in size (see text Figs. 1, 1*a*, 2 and 2*a*). Besides the vestibule remains as a closed sac by the side of the original seat of the vestibule. The recess sacciformis, a diverticulum of the infundibular region of the cavum principale—a characteristic feature of the Ranids and also *Cacosternum* (7), is however absent from *Microhyla* and *Kaloula* and only a vestige of it is noticed in *Cacopus*. Thus the infundibulum may be said to open directly into the cavum medium. The cavum medium is simple in all the three examples. Long before the narial opening closes up and the vestibule makes its appearance the infundibulum will have gained access into the cavum medium. Fig. 3 is drawn to represent the points enumerated. The blind end of the cavum medium gives origin to the ductus nasolachrymalis. The cavum inferius, like all other frogs and toads, possesses a thickened part towards the

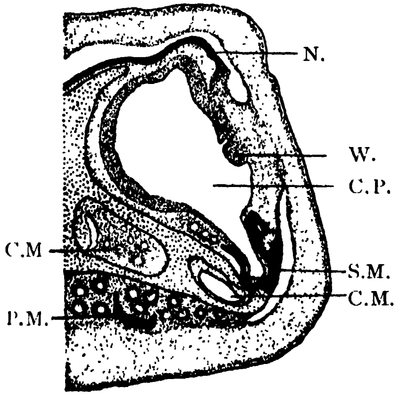


Fig. 1.

Transverse section of *Microhyla*, showing the Wulst and the septomaxillary.

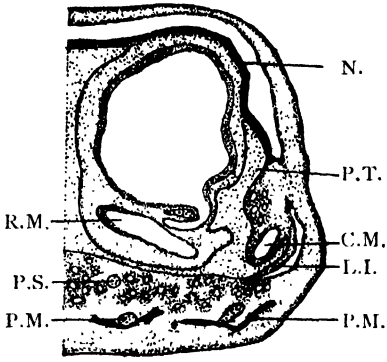


Fig. 1 a.

Transverse section of *Microhyla*, showing the nasal and the planum terminale.

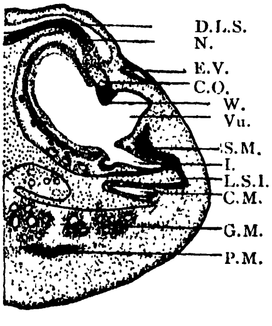


Fig. 2.

Transverse section of *Kaloula*, showing the septomaxillary.

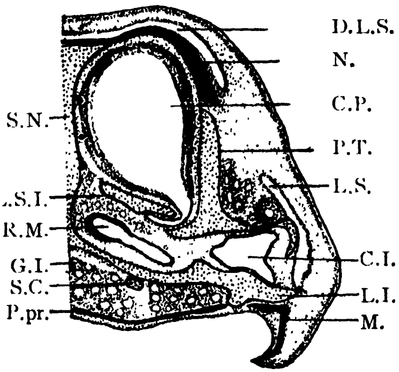


Fig. 2 a.

Transverse section of *Kaloula*, showing the nasal and planum terminale.

septum. The importance of this cavum inferius is largely due to the interpretation that is placed on this structure. Miss Lapage (9) working on the septomaxillary of the Anura remarks about *Bufo marinus* thus, "....In this species the nasal sac has three chambers similar to those found in *Rana*, namely, cavum superius, cavum medium and the cavum inferius, (Jacobson's Organ)." Thus it appears that Lapage believes that the entire cavum inferius is the Jacobson's organ, and further we read that " this homology of the cavum inferius and Jacobson's organ has been established by Wiedersheim. " Gaupp (2) homologises the recess medialis of the cavum inferius with the organ of Jacobson. Howes (10) working on the Crocodilia remarks, " there can be now no doubt that that structure sometimes referred to in the Amphibia as an organ of Jacobson is a maxillary sinus, non-homologous with the Jacobson's organ of the higher vertebrata. The latter exists in that which the known facts of development show to be the most nearly its original form among the Lacertilia." Thus, Howes is emphatic about the absence of Jacobson's organ in Amphibia. Villiers in his paper on *Cacosternum* (7) points out that the adult individual possesses a single prechoanal sac into which the choanæ no longer open. In *Phrynomerus* (6), on the other hand, the larval form has a single choanal sac which later on in the adult becomes double.

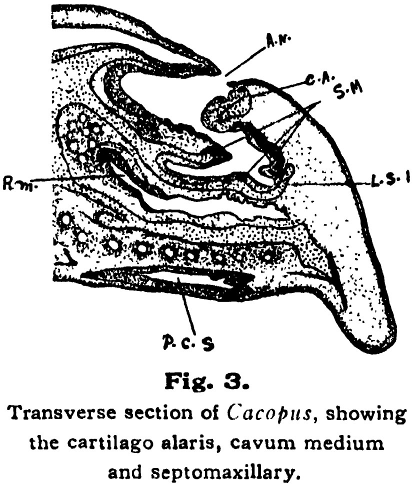
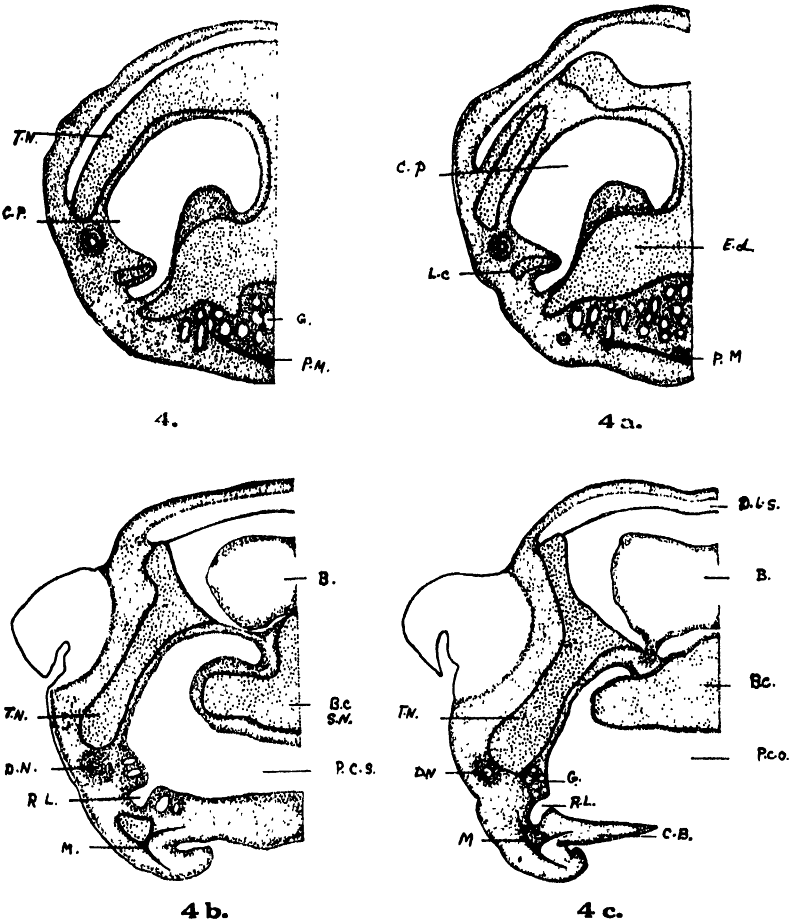


Fig. 3.

Transverse section of *Cacopus*, showing the cartilago alaris, cavum medium and septomaxillary.

In the narrow-mouthed toads under discussion, *Cacopus* falls into one group while *Kaloula* and *Microhyla* may be said to fall into another. Figures 4, 4*a*, 4*b* and 4*c* are drawn to show the transverse sections in the anterior region of the metamorphosing tadpole of *Cacopus*. The prechoanal sac is very well formed and into this sac open the two choanæ. Thus in this respect *Cacopus* closely resembles *Phrynomerus*. In the adult, however, there is only present a reminiscence of the prechoanal sac (see Fig. 3), and this sac has absolutely no relation with the opening of the choanæ. In *Microhyla*, the tadpoles do not show any trace of a prechoanal sac and the choanæ directly open into the buccal cavity. I have already mentioned that I was not



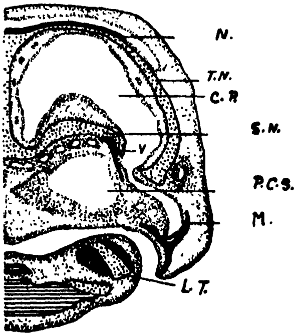
4. 4 a.

4 b. 4 c.

Figs. 4—4c.

Consecutive transverse sections of metamorphosing toadlet of *Cacopus* showing the behaviour of the tectum nasi, the formation of the prechoanal sac.

able to secure the tadpoles of *Kaloula* and at any rate, judging by the similarity of structure between *Kaloula* and *Microhyla* I can safely state that there is no prechoanal sac. In the adults of these two forms unlike *Cacopus*, I notice that the choanæ open into two sacs—the prechoanal sacs which later on fuse and open by a common opening into the buccal cavity (see text Figs. 5, 5*a*, 5*b* and 6, 6*a*, 6*b*). This character, however, has been noticed by de Villiers for *Phrynomerus* (6). He remarks, "it is more than probable that the sacs referred to above are vestiges of the organ of Jacobson." He proceeds further, "if the primitive land anamniotes possessed a buccal division of the Jacobson's organ, *Phrynomerus* represents the only known form possessing a vestige of it." Assuming this to be the state of affairs, then *Kaloula* and *Microhyla* could be very well added as the second and the third to the list, having a buccal division of the organ of Jacobson. The different views regarding the cavum inferius have already been set forth. Then, if Gaupp's view be accepted, is it that the recess medialis represents the narial part of the organ of Jacobson and the buccal part is represented in *Phrynomerus* (de Villiers) and *Kaloula* and *Microhyla*?



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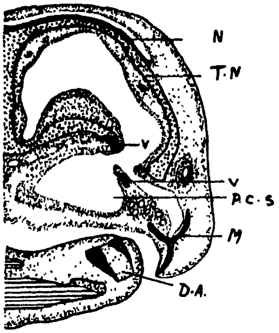
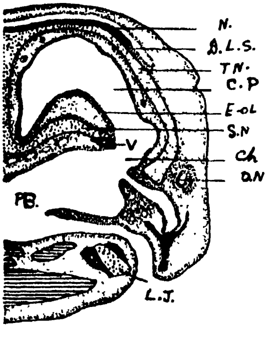


5 a.



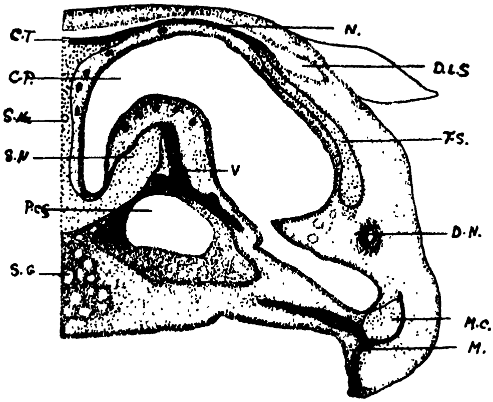
5 b.

Figs. 5—5 b.

Transverse sections of *Microhyla*, showing the formation of the prechoanal sac, and the dispositions of vomer and solum nasi.

The eminentia olfactoria are all high and elevated in all the three forms. In *Microhyla* there is a beak-like prominence in the cartilage which gives support to the eminentia towards the choanal side, and in *Cacopus* in posterior regions this cartilage assumes the shape of an inverted U (see text Fig. 5*c*).

The Bones.—Devanesan (11) has described the relation of the bones in the adult skull of *Cacopus*. He has pointed out that the sphenethmoid is extremely short and does not exhibit the prismatic shape seen in *Rana*. Further, the squamosal (the paraquadrate) and the palatine are reduced. In the alizarin preparations of the head of this animal the exact outlines of the sphenethmoid (Os en ceinture) could be very easily made out. The bone is not girdle-shaped and it is incomplete both dorsally and ventrally. It just forms the side wall of the skull in the ethmoid region and posteriorly in the side of the skull it is definitely notched. The os en ceinture which may be said to be typically Ranid makes its appearance far anteriorly and is well bent under the large nasal possessing spacious marrow cavities. As already said, the septum nasi shows gentle ossification (see text Figs. 7 and 7 *a*). The vomer is present at the base of the eminentia olfactoria with a large marrow cavity. In a more posterior region where the choana is absent from the section a vestigeal palatine is seen; the solum nasi is well ossified in continuation with the os en



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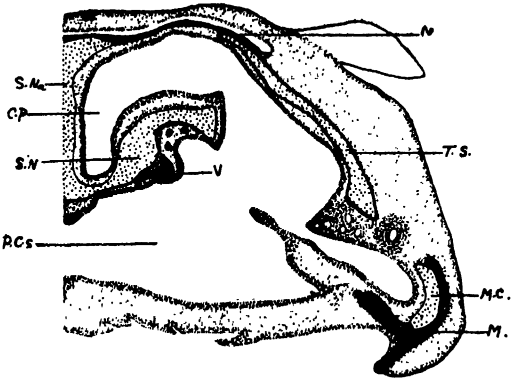
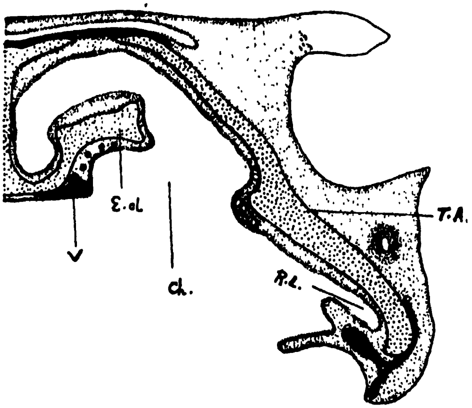


6 a.



6b.

Figs. 6—6b.

Consecutive transverse sections of *Kaloula*, showing the formation of the prechoanal sacs, solum nasi, the antorbital process and the vomer.

ceinture. The parasphenoid is seen in bits. The nasal is attenuating. All the bones, the os en ceinture, the fronto-parietals and the parasphenoid possess large marrow cavities (see text Fig. 7*a*). The sphenethmoid ossification in the case of *Microhyla* appears no sooner the choanæ close up. The vomer will also have disappeared from the sections, thus fundamentally differing from *Rana* (see text Figs. 8 and 8*a*). The tectum nasi joining the extension of the cartilago obliqua remain in this state even after the choanæ disappear. At the region where the olfactory nerves have appeared, still the posterior extensions of the cavum principale could be seen. The os en ceinture does not give rise to the dorsal and ventral extensions. In the more posterior sections the eminentia olfactoria thin out and the os en ceinture is more osseous. The palatine is absent. Text Fig. 8*a* is drawn to represent the well-developed fronto-parietals, the os en ceinture invading the tectum nasi and the cartilaginous basal part. In the region of the maximal development of the os en ceinture three pieces of cartilage are observable. Two dorsal in close apposition with the fronto-parietals and the remains on the ventral side dividing the os en ceinture into segments, the right and the left–a feature unknown

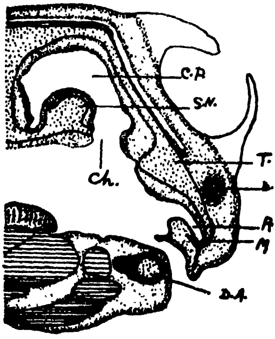
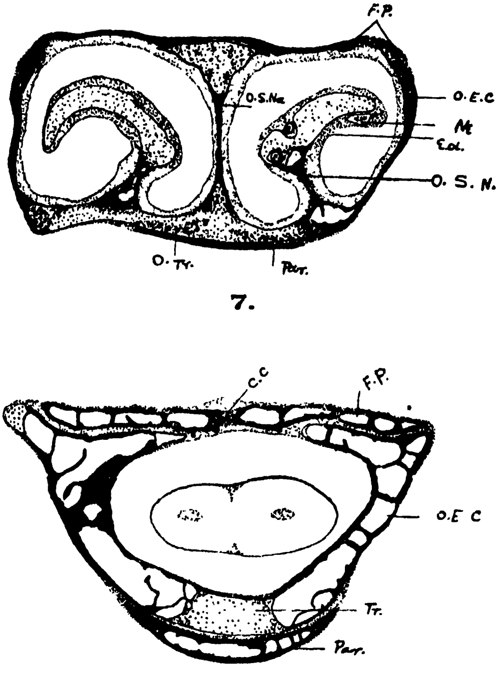


Fig. 5 c.

Transverse section of *Microhyia*, showing the solum nasi, and the antorbital process.

in the Ranidæ. In *Kaloula* a well-developed palatine is noticed in the sections. The vomer assumes enormous proportions situated just below the eminentia olfactoria. The choanæ do not seem to pierce the vomer as they do in *Microhyla* (see text Fig. 5*b*). At the level of the appearance of the olfactory nerves the fronto-parietals and the parasphenoid have made their appearance. As in *Microhyla* and *Cacopus* the fronto-parietals are very well developed being connected by a thin connective tissue—a feature in which

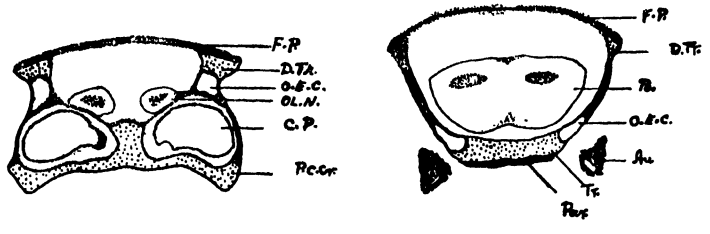


7.

7 a.

Figs. 7 and 7 a.

Transverse sections of *Cacopus* in the region of os en ceinture, showing the solar ossifications and the fully formed fronto-parietals and os en ceinture.

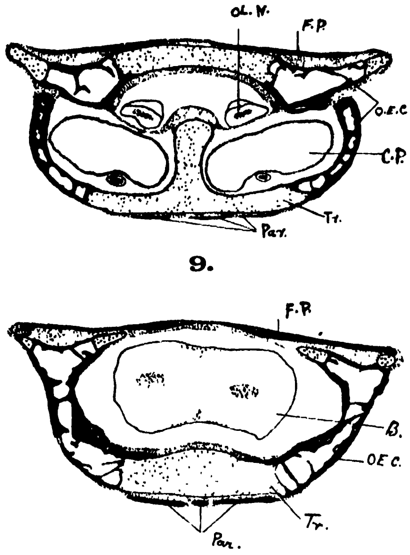


8. 8 a.

Figs. 8 and 8 a.

Transverse sections of *Microhyla* in the region of os en ceinture showing the olfactory tracts, cavum principale and the dorsal trabecular derivatives.

they differ from their South African congeners. In a region (see text Figs. 9 and 9*a*) where the olfactory lobe appears in sections a part of the cavum principale is also seen; the os en ceinture is covered over by a part of the fronto-parietals. The dorsal two pieces of cartilage which were noticed in *Microhyla* are however absent. The relation of the fronto-parietals, os en ceinture, the parasphenoid and the prootic are shown in a schematised drawing (see text Fig. 10).



Figs. 9 and 9 a.

Transverse sections of *Kaloula* showing the olfactory tracts, cavum principale and the trabeculæ between the well-formed os en ceinture.

The *Paraquadrate.*—The degenerate paraquadrate in *Cacopus* has already been referred to. In the other two examples, this bone is certainly not so degenerate as in *Cacopus*. Ecker (12) in *Rana* distinguishes three arms for this bone; the anterior, the posterior upper and the lower arms. The anterior arm as in *Rana* is free but blunt. The posterior upper arm is short and has absolutely no connection with the prootic. The lower one, however, maintains connection with the quadrato-maxillary. De Villiers in his paper on *Cacosternum* (7) remarks that "the paraquadrate is typically triradiate as in all Anura known to me; the two transverse posterior rays are normal investing bones of the quadrate cartilage and crista parotica." Here are three examples where a gradual reduction in the complexity of the paraquadrate bone could be studied, the sequence of reduction being in the order *Kaloula*, *Microhyla* and last *Cacopus*. The posterior upper arm is short in *Kaloula*, reduced in *Microhyla* and completely wanting in *Cacopus*. Even in *Kaloula* where it is conspicuous it does not bear any relation with the prootic bone as in the Ranidæ.

The palatines also observe such a sequence in reduction; *Kaloula* has a well-developed palatine, *Cacopus* a vestigeal one and *Microhyla* has lost it. Parker (23) finds that among the species of *Microhyla* an orthogenetic series could be established, ranging from forms having a palatine to forms completely devoid of it. Further, the maxillary end of the palatine is superimposed by the flat anterior terminal part of the triradiate pterygoid in *Kaloula*.

The vomer is differently shaped in all the three forms. At the palatal end of this bone there is a distinct marrow cavity in *Cacopus*, and the anterior end is divided and a part of it invests the solum nasi. The vomer does not form a vomeropalatine and in *Kaloula* the vomer is superimposed by the palatine.

The Septomaxillary.—The septomaxillary (see Figs. 1, 2 and 3) has been described by many authors and is usually met with in the region where the two lamina make their appearance. Miss Lapage (11) working on the Urodeles remarks that "the function of the bone is primarily for the origin of the musculus dilator nares accessorius." She also remarks that in forms like Triton where the muscle is reduced the bone is absent. Further Miss Lapage is definite about the point that this bone takes its origin in a cartilage both in Urodela and Anura. In support of her statements Miss Lapage adduces embryological data in pointing out on page 413, "in certain places for example, where the septomaxillary is in contact with the lamina superior of the crista intermedia, these cartilages seem to be continuous with the septomaxillary — a fact which further supports the view that the septomaxillary arises in the cartilage." De Villiers making no reference to this author remarks in his paper on *Phrynomerus* (6) on page 680, "the septomaxillary may justly be considered as a membrane bone primarily of the lamina superior crista intermedia

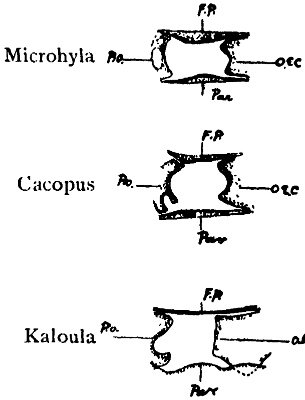


Fig. 10.

Schematized free-hand drawings of the side views of the skulls of *Microhyla*, *Cacopus* and *Kaloula*, showing the fronto-parietal, the parasphenoid, the prootic and the os en ceinture.

which is its main support. It terminates posteriorly in front of the planum terminale of the cartilago obliqua." While I disagree with de Villiers, I find in my preparations (see Figs. 1, 2 and 3) that the septomaxillary is in close contact with the cartilage not separated by any connective tissue. This bone cannot be easily made out in the metamorphosing tadpoles not until the young toad has completely lost its tail and assumed the terrestrial life for some time.

In *Cacosternum* (7) according to de Villiers the septomaxillary forms a capsule for the recess sacciformis ; in *Phrynomerus* (6) while the recess is absent in the adult it is recapitulated in the young. In the three genera under discussion the recess is entirely absent in *Kaloula* and *Microhyla*, while a vestige of it is seen in *Cacopus*, and the small infundibulum opens almost directly into the cavum medium. Nor is the recess sacciformis recapitulated in the young.

The pterygoid, as in all other Anura, is triradiate and is shifted far forwards in *Cacopus*. There is a large processus pterygoideus cartilage which is invested by the bone. This cartilage in *Cacopus* in the posterior regions becomes one with the quadrate.

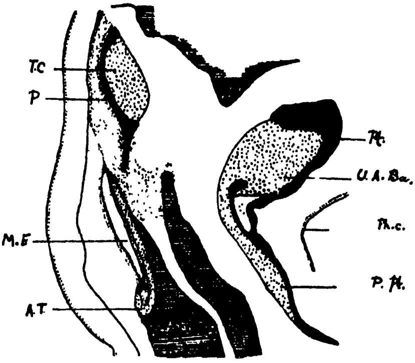
The premaxilla has three bony outgrowths. The dorsoventral blade is blunt in *Cacopus* and stops at a distance from the external narial opening. In *Kaloula* and *Microhyla* this part of the bone takes a bend and is situated anteroventrally to the anterior nares. The palatal squames are present and the right one is separated from the edentulous maxilla by a gap in *Cacopus*, while in *Kaloula* the anterior end of the maxilla invests the squame of the premaxilla. The quadratomaxillary which is a small bone extending from the posterior end of the maxilla forms a part for the suspensorium for the lower jaw.

The Nasals.—The shape of the nasal in *Cacopus* differs from the other two genera. It never extends over the planum terminale—a Ranid feature ; in *Kaloula* the nasal reaches nearly the planum terminale and in *Microhyla* it invests it (see Figs. 1*a* and 2*a*). The nasal has no connection either with the maxilla or any relation with the os en ceinture, except in *Cacopus*, where it overlies anteriorly the os en ceinture.

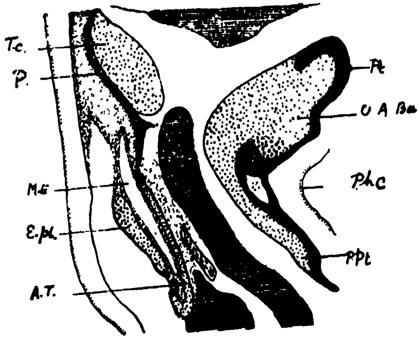
The Prootic Bone.—The optic foramen is bounded on all sides by connective tissue. A part of the anterior end of the prootic is covered by a small extension of the fronto-parietals (see Fig. 10). The shape of the prootic bone differs in the three examples.

The Frontoparietals.—This pair of bones is separated by a fairly wide notch longitudinally—much smaller than what we notice in the South African forms, connected only by a small bridge of connective tissue. In *Cacopus* the fronto-parietals project by two processes on the otic capsule, while in *Kaloula* and *Microhyla*, a very small part of the otic capsule is covered over by the frontoparietals. In all the three genera the os en ceinture is overlaid by the fronto-parietals.

The Parasphenoid.—The parasphenoid is a T-shaped bone and the anterior end of this covers a part of the os en ceinture in *Kaloula*. The relationship of the pterygoid, the paraquadrate and quadratomaxillary can be appreciated by referring to the series of figures drawn (see Figs. 11, 11*a*, 11*b*, 11*c*, 11*d* and 11*e*; 12, 12*a* and 12*b*; and 13, 13*a* and 13*b*). It is at once obvious that, as already pointed out, *Cacopus* stands apart from the other two examples.

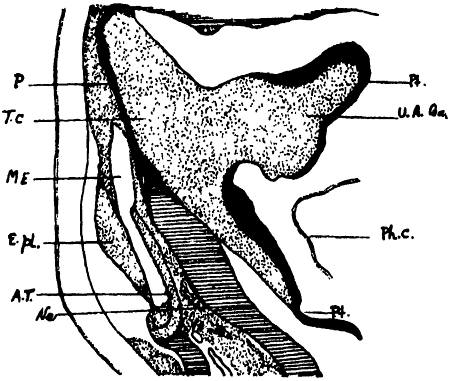


11.

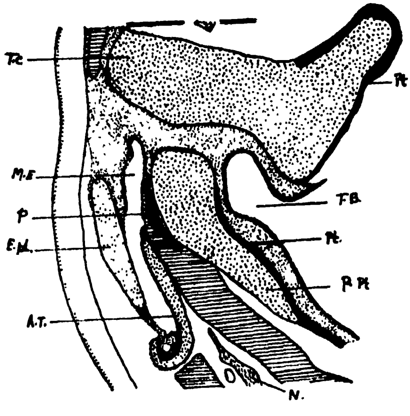


11 a.

The Ear.—A series of sections are drawn to show the relationship of the various elements in the ear region. Figs. 11 to 11*f* refer to *Kaloula* and 12 to 12*b* refer to *Microhyla*. The arrangement of parts in *Microhyla* closely resembles the South African *Cacosternum* (7) (see text Figs. 12, 12*a* and 12*b*). The paraquadrate in the transitional region forms a single investment on the epidermal side of the cartilage. I have not noticed enchondral ossification. In *Microhyla*, the processus pterygoideus is extremely small; the pterygoid has a well-developed marrow cavity. Both the upper and lower anterior horns of the process basalis which are in continuity with each other are small, the lower being invested by the pterygoid bone. The processus oticus and crista parotica are united with process basalis which is slightly above. Even in posterior sections, the pterygoid persists as a very small bone on the inner surface of pars quadrata.

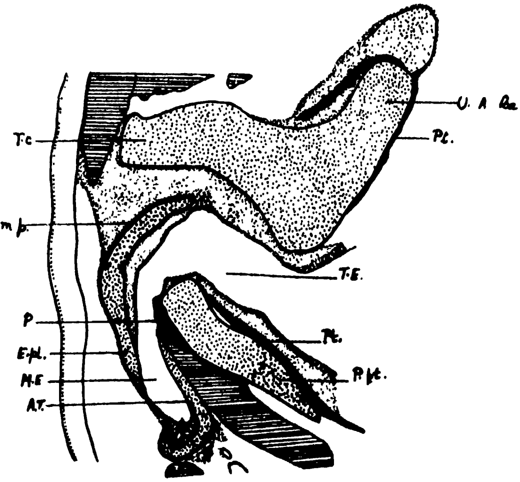


11 b.

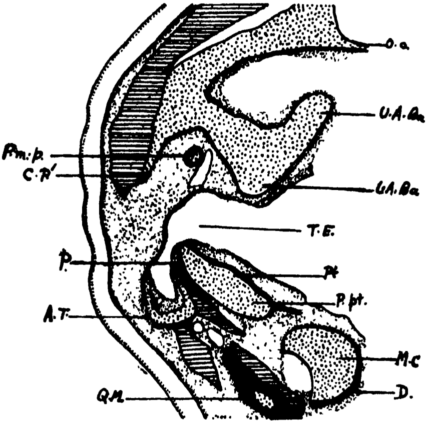


11 c.

Figure 11*b* is a section in the ear region of *Kaloula* where the transitional cartilage, processus oticus and upper anterior horn of the processus basalis are in contact with one another; the two bones paraquadrate and pterygoid are also visible. The hinder sections (11*c*) show the reduced processus oticus, the transitional cartilage and the two horns of the basal process with the pterygoid investment being separated from the combined pterygoid paraquadrate and processus pterygoideus. In *Kaloula* there is a large processus pterygoideus invested by the pterygoid bone with a large marrow cavity. Some sections of *Kaloula* show that the anterior portion of the processus basalis, usually invested by an extension of the pterygoid, is in continuity with the processus pterygoideus. Figure 11*d* is a sectional view where only the processus pterygoideus with the paraquadrate and the pterygoid are seen; further, the horns of the basal process are reduced and the crista protica is produced into a long process; the Eustachian tube is also seen. The next figure (11*e*) points out that the lower part of the annulus tympanicus has given rise to a cartilaginous process which meets the corresponding downward process from the crista parotica. In a still later section (11*f*) the pars media plectris (the bony part of the columella) has made its appearance. The processus pterygoideus has fused with the externally ossified quadrato-maxillary. By the side of this is seen the Meckel's cartilage with a small investing bone, the dermarticulare.

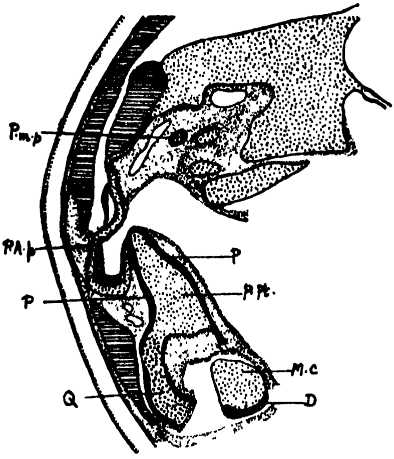


11 d.



11 e.

While these two toads resemble each other in most respects as described above, *Cacopus* stands apart and resembles *Phrynomerus* (6) and *Rana*. The relations of the paraquadrate, pterygoid and quadrato-maxillary are drawn in the series of figures 13, 13*a* and 13*b*. It must, however, be pointed out that the end of the cartilage invested by the two bones, paraquadrate and pterygoid, corresponding to the crista, remains in a large series of sections as a further part of the pterygoid bone with a well-developed marrow cavity (see Fig. 13*b*). This ossification is only lost when the crista is about to join the otic capsule.

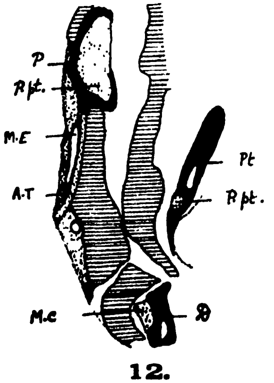


11 f.

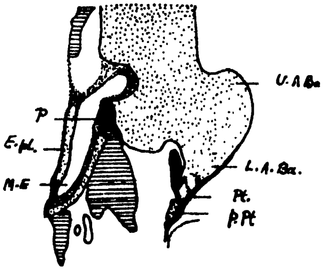
Figs. 11—11 f.

Consecutive drawings of *Kaloula* showing the relation of pterygoid, paraquadrate, quadratomaxillary, dermarticulare and the cartilages of the middle ear and pars media plectris.

Figure 13 is a section in the region where the "extra-plectral" cartilage has not yet made its appearance, and the annulus tympanicus is present with the small middle ear. Below the lower bend of the annulus tympanicus there is an unconnected piece of cartilage whose exact significance is not yet determined. Situated ventrally to this unconnected piece of cartilage, is the well-ossified quadrato-maxillary. The pterygoid with the processus pterygoideus and Meckel's with the dermarticulare are also seen. A processus quadratus is also present. The next stage (Fig. 13*a*) is when the "extra plectral" has made its appearance and the processus pterygoideus is large, being invested by the paraquadrate and the pterygoid. The figure shows the large process and the part of pterygoid with the well-ossified pars media plectris. No

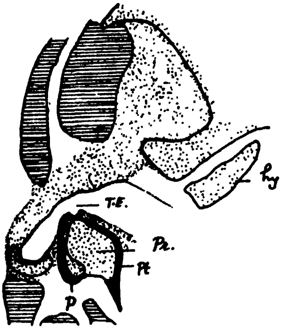


12.



12a.

cristal ossification is noticed. In brief, this cartilage, processus quadratus pterygoideus is invested by the paraquadrate, pterygoid and the quadrato-maxillary, while in the frog only the quadrato-maxillary invades the cartilage.

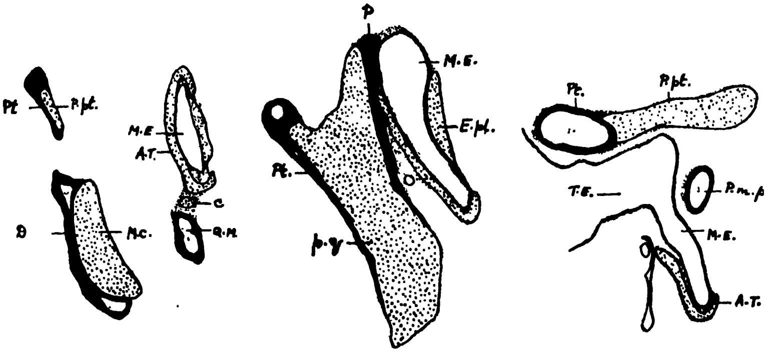


12 b.

Figs. 12—12 b.

Transverse sections of *Microhyla*, showing the paraquadrate, pterygoid and derm--articulare and the cartilages of the middle ear.

The Otic Capsule.—The prootic bone which forms the anterior boundary of the otic capsule is simple in *Kaloula* and *Microhyla*. This bone is removed far from the foramen opticus (see Fig. 10). In *Cacopus*, on the other hand, the bone is cut up into processes. The "extra-plectral" cartilage is embedded in the tympanic membrane and is attached dorsally with the osseous pars media plectris. The annulus tympanicus is incomplete dorsally, so that it is not a complete annulus. The relation of the extra-plectral cartilage, the annulus, the middle ear and the Eustachian tube are very well shown in the series of figures 11 to 11*f*, 12 to 12*b* and 13 to 13*b*. The ossification of the columella near the opercular region is different in

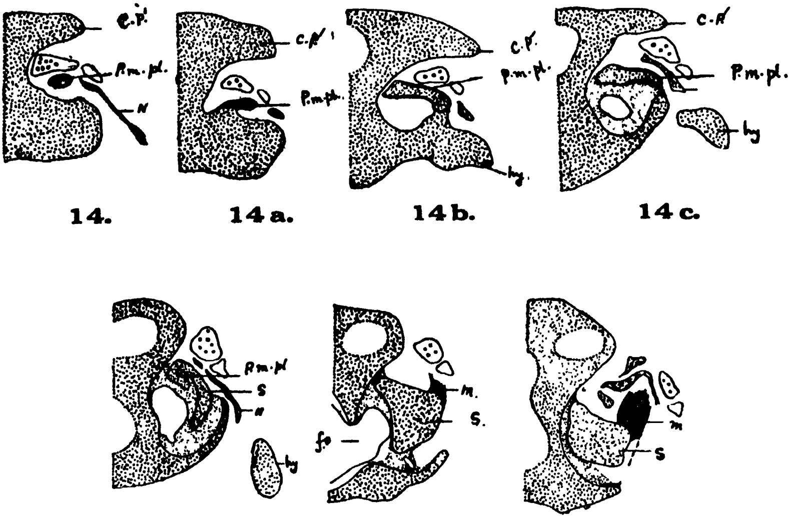


13. **13 a.** **13 b.**

Figs. 13—13 b.

Transverse sections of *Cacopus*, showing the relation of paraquadrate, the pterygoid and quadratomaxillary and the cartilages of the middle ear.

the three forms. The osseous structure is peripheral in *Microhyla*, slightly internal in *Kaloula* and definitely internal in *Cacopus*. The attachment of this part of the columella with the otic capsule is also different. While it is terminal in *Cacopus*

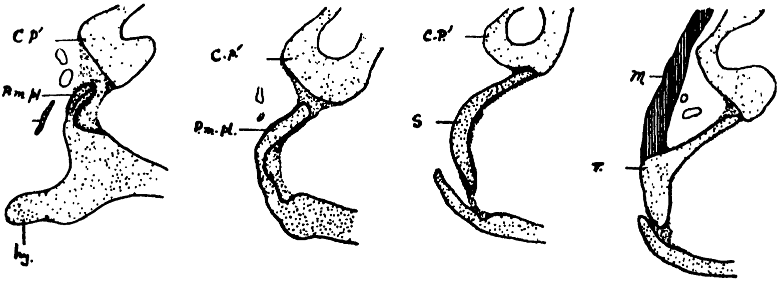


14. 14 a. 14 b. 14 c.

14 d. 14 e. 14 f.

Figs. 14—14 f.

Transverse sections of *Kaloula*, showing the attachment of the pars media plectris, the operculum and the hyale.

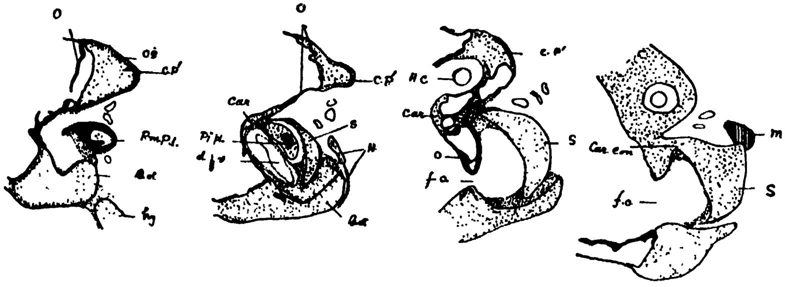


15. 15 a. 15 b. 15 c.

Figs. 15—15 c.

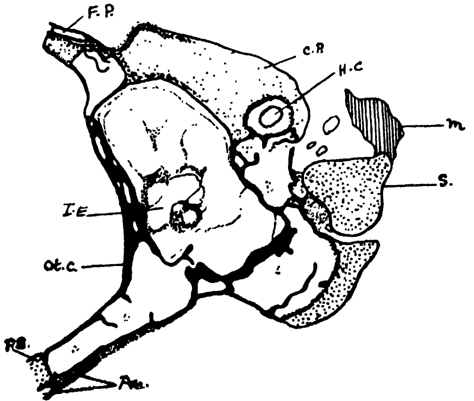
Transverse sections of *Microhyla*, showing the attachment of pars media plectris, the operculum and the opercular muscle.

and *Kaloula*, it is removed far from the attachment of the hyoid in *Microhyla*. The columella is overlain with the jugular vein and the seventh nerve.



16. **16 a.** **16 b.** **16 c.**

In all the three, the operculum (the stapes) is cup-shaped and covers the fenestra ovalis. This operculum is never attached either to the upper part (crista parotica) or the lower lip of the fenestra ovalis in *Kaloula* (see text Figs. 14 to 14*b*) and *Microhyla* (see text Figs. 15 to 15*c*) while in *Cacopus* it depends from the crista parotica as shown in the Fig. 16*c* (see text Figs. 16, 16*a*, 16*b* and 16*c*). In all the three the operculum carries a well-developed knob for the attachment of the opercular muscle. The otic capsule is feebly ossified in *Kaloula* and *Microhyla*. In *Cacopus*, on the other hand, extensive ossification occurs ; even the septum separating the brain cavity from the otic, is heavily ossified with the large marrow cavities in the bones (see text Fig. 16*d*).



16 d.

Figs. 16—16 d.

Transverse sections of *Cacopus*, showing the attachment of pars media plectris, the operculum and its attachment with crista and the extensive ossification of the otic vesicle.

DISCUSSION AND SUMMARY.

The edentulous nature of the premaxillæ has been much used in taxonomy and is believed to be a distinguishing feature of the group Engystomatidæ. This cannot be very well relied upon for one of the South African Brevicipitid toads, *Cacosternum*, possesses teeth on the premaxilla. Further, de Villiers questions the propriety of the inclusion of the *Cacosternum* under Engystomatidæ. Like the other South African forms these lack the procorocoid bone. On account of the loss of it the corocoid assumes greater proportions. Like the Ranids *Cacopus* possesses both the prenasal cartilages while *Microhyla* and *Kaloula* have only the superior. Moreover, the palatal squame of the premaxilla is separated by a gap in *Microhyla* and *Cacopus* while the premaxilla invades the squame in *Kaloula*. It is peculiar, however, that *Kaloula* should differ from *Microhyla* in such minor details, for in the characters that are going to be enumerated hereafter one will notice the close similarity between the two.

The disappearance of a typically Ranid feature—the recess sacciformis ought to be mentioned. The septomaxillary which has been definitely pointed out to be cartilage bone does not give attachment to any muscles as pointed out by Miss Lapage for Urodeles. Unlike the Ranids the plica is suspended from the cartilago obliqua and not from the tectum nasi.

The Ranid eminentia olfactoria is always known to be flat and low. In the case of all these three examples it has been pointed out that the eminentia are very high and moreover carry a beak or a bent process in *Kaloula* and *Microhyla*, while in *Cacopus* in the posterior regions the eminentia assume the shape of an inverted U. In this respect the South African *Cacosternum* differs from all these three.

The vomers are very well developed in *Cacopus* and *Kaloula*, and feeble in *Microhyla*. A process from the anterior end of the vomer invades the nasal capsule and in *Microhyla* the choanæ also, thus differing in these respects from *Rana* and *Cacosternum*. The bone is edentulous and carries a marrow cavity. Further, no fusion of the vomer is ever noticed with the palatine, thus no vomeropalatine, as seen in *Phrynomerus*, is ever formed. The palatine, as has already been pointed out, is very well developed in *Kaloula*, vestigeal in *Cacopus* (Devanesan) and is completely absent from *Microhyla*. M. Smith (23) figures the ventral view of the skull of *Kaloula* *pulchra* and remarks on page 120 thus, " palatine much reduced, its inner extremity underlying the vomer." In the alizarin preparations that I have examined the palatine is well developed covered by a part of the vomer at the inner end and the pterygoid, at the outer end. Thus there appears to be a gradual reduction in this investing bone in these three genera. Here again there is a divergence of character between *Microhyla* and *Kaloula*. Incidentally in the possession of a well-developed palatine invaded by a part of the pterygoid in *Kaloula*, links it with the two examples *Rana* and *Cacosternum*. Possibly the reduction of the palatine and the disposition of the vomer are to be regarded as purely secondary.

The nasals are never Ranid in character; it is only in *Cacopus* that a part of the nasal covers a part of the os en ceinture. In *Phrynomerus* and *Rana* the nasals leave little of the anterior portion of the os en ceinture exposed. The fronto-parietals are so extended anteriorly in these three South Indian narrow-mouthed toads, that the inwardly flexed part of the os en ceinture is covered over in turn by the fronto-parietals.

The os en ceinture is typically paired in all the three examples unlike *Rana*. In certain regions the free dorsal ends of the os en ceinture persist as cartilage while at other regions the dorsal ends are ossified. These cartilaginous trabecular derivatives are characteristic of these forms and also *Phrynomerus*, while in *Rana*, it is entirely osseous.

The occurrence of the two prechonal sacs in *Microhyla* and *Kaloula* and the occurrence of a vestigeal one in *Cacopus* has already been stressed. In the case of *Phrynomerus* the single anlage with the choanæ opening into it develops in the adult into a sac which bears no relation with the choanæ. The exact homology of these sacs is rather difficult to elucidate; however, it has been pointed out that these sacs in *Kaloula* and *Microhyla* may correspond with the buccal part of the organ of Jacobson, while the recess medialis of the cavum inferius would form the narial part of the organ.

The fronto-parietals are very well developed, more extensively than in the case of *Phrynomerus* and *Cacosternum*. The two frontoparietals on either side are united by a small bridge of connective tissue and the fronto-parietal foramen is therefore minimised. In South African forms the connective tissue bridge assumes enormous proportions since the fronto-parietals are very feebly developed.

The optic foramen in South Indian Engystomatidæ is never bounded by the posterior extension of the os en ceinture.

The ossification of the otic capsule is exaggerated in *Cacopus* and, as already pointed out, the septum between the otic and the brain cavity is also ossified possessing marrow cavities. Closely associated with this extensive ossification mention must also be made of the ossification in the narial region. The septum nasi, while in earlier sections, shows patches of ossification, in the posterior regions becomes definitely ossified. Moreover, the solum nasi is also ossified. Such an extensive ossification I have not noticed in any frog or toad that I have examined. De Villiers working on the cranial osteology of *Hemisus mormoratus* remarks on page 316, "At the outset it should be pointed out that *Hemisus* has the most extensively ossified chondrocranium among the Anura. Although the os en ceinture in some genera (*Cacosternum* and *Anhydrophryne*) tends to be prolonged into the tectum, *Hemisus* is probably the first anuran for which ethmoidal solar ossification has been described." Certainly, *Cacopus* should be included in the list as an example where ethmoidal solar ossification also occurs. This fairly extensive ossification in the cranium of this narrow-mouthed toad must be closely correlated with the habits of life. It is said that this toad lives buried under earth six to seven feet for at least six months in the year during summer. When favourable conditions like the rainy season supervene these animals come out to breed. It is definitely known that this animal does not use its head in burrowing, for the hind feet are well supplied with tubercles which aid the animal. Possibly, the vestigeal condition of the paraquadrate and the palatine and the shifting forward of the pterygoid must be compensated for and this is done by the complete ossification of the various parts enumerated. *Kaloula* and *Microhyla* dwell usually in wet earth and do not generally reach great depths, and since the disposition of the paraquadrate and pterygoid are normal such a wide ossification as occurs in *Cacopus* is unnecessary.

The paraquadrate is small, with no processes in *Cacopus*, and in *Kaloula* and *Microhyla* the bone possesses one small projection, towards the otic capsule. Further, this bone is in close proximity with the unossified crista in *Cacopus*; in *Microhyla* and *Kaloula* the crista is cartilaginous and is enveloped partly by the paraquadrate.

The pterygoid invests partly the process pterygoideus and later remains as an unossified part of the process basalis when the Eustachian tube makes its appearance. The pterygoid invades the processus in *Microhyla* and *Kaloula*.

The quadrato-maxillary is a well ossified bone investing the process quadratus. In *Cacopus* this articular portion becomes one with the process pterygoideus. In *Kaloula* the processus quadratus becomes one with processus pterygoideus and thus all the three, quadrato-maxillary, paraquadrate and pterygoid, invest this cartilage, while in *Rana* only the quadrato-maxillary invests it.

The 'pars ascendens plectri' is absent from all the three genera. However there is a cartilage establishing connexion between the ventral division of the annulus tympanicus (and not pars externa) and the crista parotica is to be seen only in *Kaloula*. In my preliminary communication this cartilage was inadvertently labelled pars ascendens.

While the relation of bones and cartilages in the ear region of *Cacopus* resembles *Phrynomerus*, the other two examples stand apart and resemble the more Ranid *Cacosternum*. Like their South African relatives these three forms have a 'hidden tympanum' and the skin is unmodified in the region of the tympanic membrane. The exact homology of the pars media plectris (columella) and the operculum (stapes) is described in various ways. In the Ranidæ the osseous medio-stapedial process bears an outer portion embedded in the tympanic membrane—the extra-stapedial cartilage, and internally from the mediostapedial process fitting into the fenestra ovalis is another cartilaginous process—the interstapedial. In the Engystomatidæ, on the other hand, the pars media plectris expands into a cartilaginous oval cartilage embedded in the tympanic membrane. As de Villiers remarks, if the view that the stapes and columella of Sauropsida are homologous with the plectrum and operculum of Anura (Gaupp), then the nomenclature of the plectral apparatus till now in vogue becomes untenable; and the cartilage embedded in the membrane is to be rightly called "extra-plectral" homologous with the extra-columella of Reptilia.

The operculum is well developed in all the three forms; it is but natural to expect this development since all the three toads are typically terrestrial. This is in accordance with the observation of Versluys (20). One point of great difference between the attachment of stapes in *Cacopus* from the other two examples, deserves mention. The crista parotica is attached to the stapes only in *Cacopus*. Graham Kerr in his *Text-book of Embryology* (1919), page 345, points out that " the inner end of the columella (stapes) fits into the fenestra ovalis. It is for a time, during prochondral or cartilaginous stages or both, continuous with the wall of the auditory capsule and is probably to be interpreted as a portion of this wall which has become separate and moveable." Whether the stapes is merely an extension of the crista, a view supported by the adult *Cacopus* or is a chondrification in the capsular membrane closing the fenestra ovalis (Villy. 24.) requires a little more detailed study.

KEY TO THE LIST OF ABBREVIATIONS USED IN THE TEXT.

A. N.	..	Anterior nares.
A. T.	..	Annulus tympanicus.
Au.	..	Augendrüse.
B.	..	Brain.
B. C.	..	Basis crani.
B. C. S. N.	..	Basis crani and septum nasi.
B. ot.	..	Base of the otic capsule.
C.	..	Cartilage.
C. A.	..	Cartilago alaris.
Car. Con.	..	Cartilaginous connexion.
C. B.	..	Remains of the tissue between the prechoanal sac and buccal cavity.
C. C.	..	Connective tissue attaching the frontoparietals.
Ch.	..	Choana.
C. M.	..	Cavum medium.
C. O.	..	Cartilago obliqua.
C. P.	..	Cavum principale.
C. P′.	..	Crista parotica.
D.	..	Dermarticulare.
D. A.	..	Lower Jaw.
d. f. v.	..	Ductus fenestra vestibuli.
D. L. S., L. S.	..	Lymph sac.
D. N.	..	Ductus nasolachrymalis.
D. Tr.	..	Dorsal part of the trabecular derivative.
E. ol.	..	Eminentia olfactoria.
E. pl.	..	Extraplectral.
E. V.	..	Ectodermal vesicle.

f. o.	Fenestral ovalis.
F. P.	Frontoparietal.
G., G. M.	Glands.
H. C.	Horizontal Canal.
hy.	hyoid.
I.	Infundibulum.
I. E.	Internal Ear.
L. A. Ba.	Lower anterior part of the process basalis.
L. I.	Lamina inferior cristæ intermediæ.
L. J.	Lower Jaw.
L. S. I.	Lamina superior cristæ intermediæ.
M.	Maxilla.
m.	Opercular muscle.
M. C.	Cartilage.
M. E.	Middle Ear.
N.	Nasal.
Ne.	Nerve.
O.	Ossified part of the otic capsule.
O. E. C.	Os en ceinture.
Ol. N.	Olfactory nerve.
Os.	Ossifications in the cartilage.
O. S. N.	Ossified solum nasi.
O. S. Na.	Ossified septum nasi.
O. Tr.	Ossifications in the trabeculæ.
P.	Paraquadrate.
p. A. p.	Cartilaginous connexion.
Par.	Parasphenoid.
P. B.	Union of the prechoanal sac and the buccal cavity.
P. C. O.	Opening of prechoanal sac into the buccal cavity.
P. C. S.	Prechoanal sac.
Ph. C.	Buccal cavity.
P. M.	Premaxilla.
P. m. p.	Pars media plectris.
P. O.	Process oticus.
P. pt.	Processus pterygoideus.
p. q.	Processus quadratus.
Pt.	Pterygoid.
Q. M.	Quadratomaxillary.
R. L.	Recess lateralis.

R. m.	Recess medialis.
S.	Operculum.
S. G.	Glands.
S. M.	Septomaxillary.
S. N.	Solum nasi.
S. Na.	Septum nasi.
T. A.	Antorbital Process.
T. C.	Transitional cartilage
T. E.	Tuba Eustachi.
T. N.	Tectum nasi.
Tr.	Trabeculæ.
T. S.	Part of antorbital cartilage.
U. A. Ba.	Upper anterior part of process basalis.
V.	Vomer.
Vu.	Vestibule.
W.	Wulst.

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THE CRANIAL OSTEOLOGY OF *OPHIOCEPHALUS STRIATUS*—BLOCH.

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INTRODUCTION.

During the early part of last year Professor C. R. Narayan Rao suggested to me that it would be worth while to work out the osteology of an Indian Teleost. The snake-headed fish *Ophiocephalus* has a very wide distribution throughout India and is easily available for class work in any of the colleges. *Ophiocephalus striatus* has been chosen for study on account of its large size and it may be pointed out here that there is not any fundamental osteological difference between this and the members of other species. The author deals only with the study of the skull of *Ophiocephalus* in the present communication. *Ophiocephalus* resembles *Scomber* considerably in its cranial organization.

Cranium.

The cranium is, more or less, compressed and slopes, on the upper side, from behind forwards. It is broad in the posterior region and tapers anteriorly. The bones on the dorsal surface are flat, broad and are compactly articulated with one another. They are sculptured with fine radiating ridges and are superficial being covered over by mere scales. Posterior to the supraoccipital bone the cranium slopes backwards giving attachment to the trunk muscles. There are two epiotic lamellæ and a small supraoccipital process. The parasphenoid axis is straight except for a short anterior deflection of the vomer.

In the *ethmoid region* the median thick *supraethmoid* (mesethmoid) separates completely the two laterally situated ectethmoids. The supraethmoid is very poorly ossified and much of the cartilage exists in the middle region of the bone. The anterior portion is rounded and fits into a notch on the dorsal surface of the vomer. It articulates posteriorly with the frontals and ventrally with the parasphenoid. Each *ectethmoid* is pierced by the olfactory nerve and the olfactory bulb will be situated just in front of this opening. It has articular surfaces for the palatine and the lacrymal. The postero-dorsal portion of this bone articulates with the anterior end of the frontal. On either side of the supraethmoid and opening posterolaterally is a deep, distinct recess formed partly by this bone and partly by the ectethmoid. These are the "anterior myodomes" which lodge and give attachment to the oblique muscles of the eye. On the ventral portion of the ethmoid region is a prominent *vomer* which extends in front

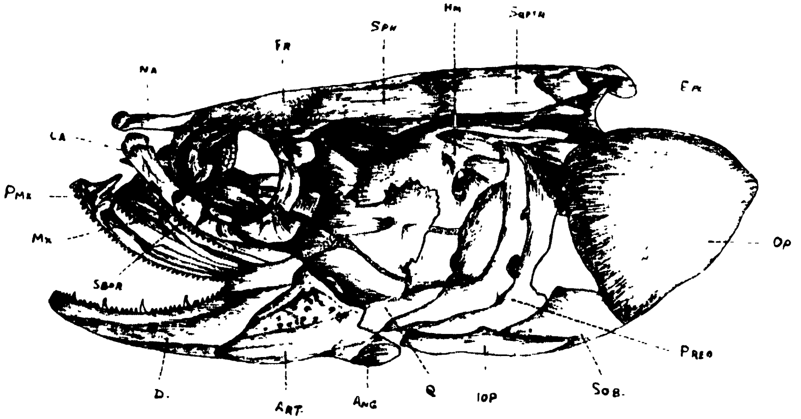

Fig. 1.

The Skull of *Ophiocephalus striatus.*

of the supraethmoid.* The broad anterior portion of the bone is toothed and it tapers to a point posteriorly by which it fits into a notch in the parasphenoid.

Posterior to the ethmoid region is the *sphenoid region* of the cranium. Here, the *orbitosphenoid* is absent. Hence there is no cartilaginous or osseous interorbital septum. The orbits are in wide communication with each other in a dry skull. The *suprasphenoid* has the characteristic Y shape. The shank of the Y which rests on the parasphenoid is thick and short and sends out dorsolaterally two arms which are broad and each is divided into an anterior and a posterior portion. The anterior portion articulates with the alisphenoid and the posterior with the prootic of that side forming a tubular passage (Fig. 6) for the recti muscles of the eye as they proceed to the posterior myodome. The floor of this passage is formed by the parasphenoid. The *alisphenoids* are small and form the side walls of the cranial cavity above the suprasphenoid and in front of the trigemino-facial foramen. They articulate laterally and posteriorly with the prootics and above with the frontals. The *sphenotics* are flat bones on the dorsal surface outside the frontals and in front of the squamosopterotics. It has no direct otic relationship. The chondral portion of the bone lies immediately over the recess (in the prootic) which lodges

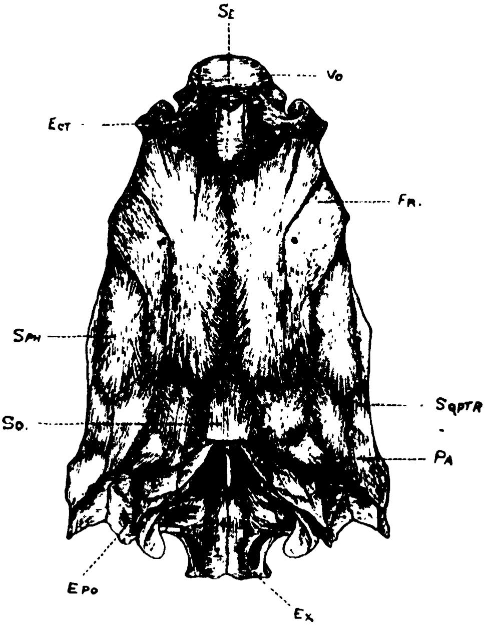

Fig. 2.

The dorsal view of the cranium of *Ophiocephalus striatus.*

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* The vomer and the parasphenoid belong, strictly, to the buccal series but since they are firmly united with the cranium they are treated here.

the ampulla of the anterior semicircular canal. The dermal part lodges a portion of the lateral line canal. On the outer surface of the bone is a concavity which is the anterior portion of the cranial articular facet for the hyomandibular. The *parasphenoid* is a long bone broad in the middle and narrow at the two ends. It extends from the vomer as far back as the vertebral articular surface of the basioccipital. On the posterior half of the bone there is an oval toothed area (Fig. 3).

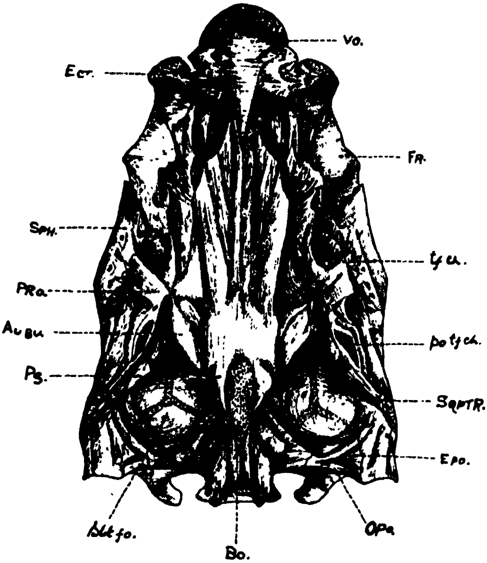

Fig. 3.

The ventral view of the cranium of *Ophiocephalus striatus.*

The *auditory region* of *Ophiocephalus* has undergone considerable modification. The *prootics* are very large bones. Each extends from the exoccipital almost to the anterior end of the alisphenoid and on the upper side it forms the lower boundary of the articular facet for the hyomandibular. The outer wall of the auditory capsule is, more or less, completely formed by the prootic, the other otic bones being excluded. The prootic is pushed out ventrolaterally to form a prominent auditory bulla. Externally there is a thick process which extends dorsolaterally from about the middle of the bone. Here, some amount of unossified cartilage is present. The anterointernal portion of the bone is pierced by a fairly wide opening which gives passage to the trigeminal and the palatine branch of the facial nerve. Immediately posterior to this is a smaller opening through which passes out the hyomandibular branch of the VII nerve. Internally the bone sends inwards a small, thin lamella over the parasphenoid which meets a similar fellow of the other bone in the middle region.

forming the roof of a deep recess. This recess is the posterior myodome which lodges and gives attachment to some of the recti muscles of the eye. The inner surface of the bone in the anterior portion is vacuolated. The interior of the auditory bulla is spacious and smooth and lodges the sacculus. There is a large oval ear ossicle. Slightly posterodorsal to the trigemino-facial foramen there is a recess which lodges the anterior portion and the ampulla of the anterior semicircular canal (Fig. 6). The external semicircular canal is directed upwards posterolaterally and passing through the epiotic, curves round anteriorwards and traverses through the chondral portion of the squamosopterotic and finally enters the auditory capsule through an opening situated in the prootic posterior to the recess of the anterior semicircular canal. The ampullæ of these two canals are close to each other. The posterior semicircular canal is pressed between the sacculus and the inner wall of the auditory bulla. The impression of this canal and its ampulla can clearly be seen on the inner surface of the ear ossicle. The internal carotid artery passes forward over the posterior half of the parasphenoid between its two lamellæ and just below the auditory bulla divides into two. The outer branch pierces the prootic in front of the auditory bulla and enters the trigemino-facialis chamber, while the inner branch opens into the cranial cavity lateral to the mouth of the myodome and proceeds to the orbit of that side.

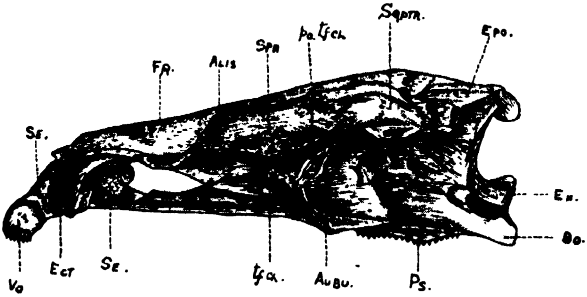

Fig. 4.

The side view of the cranium of *Ophiocephalus striatus.*

Trigemino-facialis Chamber (Figs. 3 & 4).—The thick dorsolateral process of the prootic encloses a short horizontal canal with a wide anterior and a narrow posterior opening. Allis describes this as the "Trigemino-facialis chamber" in

Scomber scomber. The trigeminal and the palatine branch of the VII nerve emerge out of the cranium through the anterior opening and the hyomandibular branch of the VII through the posterior opening of this chamber. And also the jugular vein (*vena capitis lateralis*) passes through the chamber. It is typically developed in the higher Teleostomi (Goodrich).

The Myodome.—The anterior myodomes have already been described. The posterior myodome (Fig. 6) is roofed by the prootic lamellæ and floored by the parasphenoid. It has a wide anterior opening and is closed behind. The hypophysis of the brain lies just in front of the opening of the myodome. The anterior rectus muscle is attached to the anterior portion of the suprasphenoid while the other three—posterior, superior and inferior—recti pass beneath the suprasphenoid-prootic bridge and enter the myodome.

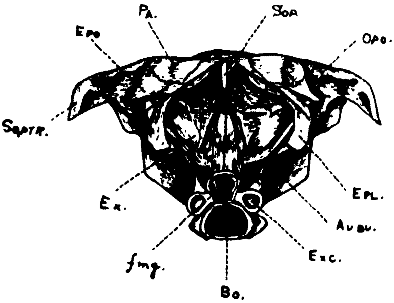

Fig. 5.

The posterior view of the cranium of *Ophiocephalus striatus.*

The *squamosopterotic* is a flat bone at the posterolateral corner of the cranium. It is considerably pushed outside and is excluded from the cranial cavity. The lower chondral part contains a portion of the external semicircular canal and the upper dermal part contains a portion of the lateral line canal. The outer surface of the bone possesses the posterior portion of the articular facet for the hyomandibular. The *epiotics* are also pushed backwards and do not contribute to the wall of the cranial cavity. Each is situated between the squamosopterotic and exoccipital and behind the parietal and supraoccipital. A portion of the external semicircular canal passes through this bone. It sends out a thin lamella posterointernally which gives attachment to the trunk muscles. The *opisthotic* (Figs. 3 & 5) is a very small vestigeal bone situated on the ventral side at the posterolateral corner of the epiotic. It has a small articular facet on which the reduced lower limb of the posttemporal articulates.

On either side of the cranium and situated slightly posterodorsal to the auditory bulla is a wide shallow fossa which by its position can be termed the "Subtemporal fossa" (Fig. 3). It is roofed over by the supraoccipital, epiotic and the squamosopterotic. The subtemporal fossa along with a lamella of the hyomandibular forms the wall of the secondary air breathing chamber of the fish.

The dorsal surface of the *occipital region* slopes backwards and inwards and gives attachment to the anterior end of the trunk muscles. The *supraoccipital* is shifted considerably forwards and it roofs the cranial cavity above the posterior myodome. It has a thin, small supraoccipital process. It sends out on either side a thin lamella which meets similar ones, underneath the parietal, from the squamosal and the epiotic. These three lamellæ are separated from one another by a thin strip of cartilage. The *exoccipitals* are long and meet each other a long distance on the dorsal side. They do not meet below the foramen magnum. The foramen magnum is long and tunnel-like the floor of which is formed by the basioccipital while the rest of its boundary being formed by the exoccipitals. Each presents laterally a thick oval secondary vertebral articular surface (Figs. 4 & 5). On the anterior portion of the bone there are the glossopharyngeal and vagus foramina, while in the hinder region by the side of the articular process is a (single or sometimes divided) foramen for the hypoglossal nerve. The *basioccipital* is thick and presents posteriorly a large oval concave articular surface for the vertebral column. The cavum cranii in front of the supraoccipital is roofed by two large *frontals*. Behind the frontals and on either side of the supraoccipital is a flat parietal. The *parietals* are completely separated

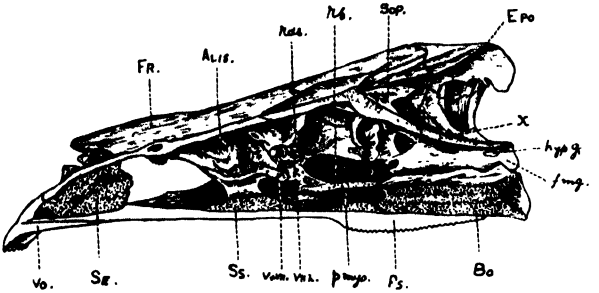

Fig. 6.

The median view of the bisected cranium of *Ophiocephalus striatus.*

by the supraoccipital. The cranial cavity is wide in the hypophysial region and narrows forwards and backwards.

The cranium, in general, is fairly well ossified except for the supraethmoid and the interior of the sphenoid and the otic bones which remain incompletely ossified. There are thin strips of cartilage between the cartilage bones in the posterior portion of the cranium.

2. *Lateral Line System.*

The lateral line canal from the posttemporal enters the loose supratemporal and divides into two. The inner branch is very small and passes to the parietal for a short distance and the outer branch enters the squamosopterotic and immediately branches into two, the outer descending into the preopercular enters the mandible forming the preopercular-mandibular branch and the inner branch proceeds forwards and passes through the sphenotic. Immediately in front of the sphenotic it again divides into the outer-suborbital branch which passes through the suborbitals and the inner supraorbital branch which enters the frontal. In the anterior portion of the frontal it divides again, the inner branch meets in the middle line a similar fellow from the other side and the outer proceeds anteriorwards, passes through the nasal and opens to the exterior.

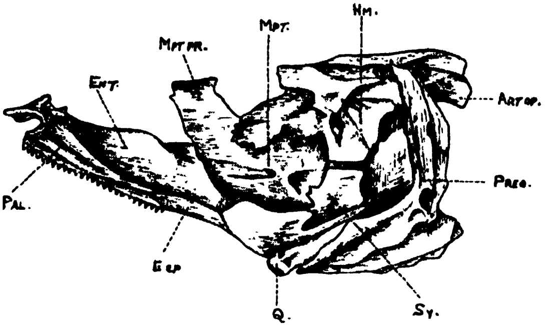

Fig. 7.

The palatoquadrate bar, hyomandibular and the preoperculum of *Ophiocephalus striatus*.

3. *Temporal and Preopercular Series.*

The *supratemporal* is a thin loose tubular bone situated partly on the posterior portion of the squamosopterotic. The posttemporal is also a loose bone with a thin epiotic limb and a very small lower limb by means of which it articulates with the opisthotic. There are no subtemporals. The *preoperculum* is thin, long and curved and articulates with the symplectic and the quadrate.

4. *Circumorbital Series.*

This consists of five small *suborbitals* and the anteriormost *lacrymal* (Fig. 1). The latter is long and articulates on the ectethmoid. They are tubular and each contains a portion of the suborbital branch of the senory canal. The *nasals* are fairly broad and extend slightly in front of the supraethmoid. Each contains the anterior part of the supraorbital branch of the sensory canal.

5. *Maxillary Series* (Fig. 1).

The *maxillaries* are edentulous and do not form the margin of the upper jaw. They are long curved bones which are posterior and parallel to the premaxillaries. It is flat at the posterior end. The anterior portion is thick with two knobs by which it is attached to the lateral side of the anterior process of the premaxillary by means of ligament. Just outside the anterior end it is connected with the palatine by another ligament.

The *premaxillaries* form the complete margin of the upper jaw. They are also long, curved and fairly flat bones. The anterior end of each is thick and it becomes gradually thinner and flexible (fibrous in nature) towards the posterior end. The whole of its ventral surface is covered with fine, sharp, curved teeth. At the anterior end is a dorsoposteriorly directed process which is divided into two portions, the inner articulating with the upper surface of the supraethmoid and the outer on the vomer. The premaxillaries are attached in the middle to each other by thick ligament. The premaxillaries, with the maxillaries, is capable of certain amount of upward and downward movement on the anterior face of the cranium.

6. *Palatoquadrate-hyomandibular Series* (Fig. 7).

The anteriormost element of the palatoquadrate bar is the *palatine* which is fairly broad in the anterior portion and tapers posteriorly. The ventral surface is covered with sharp curved teeth. The bone is thick on the upper side of the anterior portion and sends out an anterior process which fits over the maxillary of that side. Just outside this process is a knob which gives attachment to the ligament that connects this bone with the maxillary. Between these two is a notch which fits over the anterior portion of the ectethmoid. It is attached on its upper portion to the thin lower margin of the entopterygoid and on its posterior end with the ectopterygoid. The *entopterygoid* is a thin lancet-shaped bone. It articulates anteriorly with the palatine, ventrally with the ectopterygoid and posteriorly with the metapterygoid and the quadrate. The *ectopterygoid* is thick rod-like and is situated between the palatine and quadrate and below the entopterygoid. The *metapterygoid* is a large bone situated over the quadrate in front of the symplectic. It sends out a flat and fairly thick process anterodorsally which clearly articulates on the ventral portion of the frontal just in front of the sphenotic. The upper margin of this process is incompletely ossified. It could, more or less, be regarded as the 'basal process'. But the topographical relations of this process and the 'processus ascendens' of Dipnoi and Tetrapoda, with the nerves and blood vessels, are exactly identical. Discussing about the latter Goodrich says " Yet another important process is present in Dipnoi and Tetrapoda. It is the *processus ascendens* typically developed from the pterygoid region of the palatoquadrate bar, near the origin of the basal process as a dorsal cartilage passing vertically upwards between the profundus nerve and the maxillary branch of the trigeminal. and laterally to the *vena capitis lateralis*. Its upper end fuses with the orbital wall of the cranium in Dipnoi. It is found neither in chondrichthyes nor in the modern Teleostomi except possibly as a vestige. Whether it occurred in early primitive Teleostomes is uncertain." The metapterygoid process of *Ophiocephalus* is also situated just outside the *vena capitis lateralis* between the profundus nerve and the maxillary, mandibular branches of the trigeminal. The upper portion of the metapterygoid is overlapped by the thin anteroventral margin of the hyomandibular. It is separated from the quadrate by a strip of cartilage. The *quadrate* is, more or less, triangular, the ventral apex forming the thick articular surface for the mandible.

The pterygoquadrate bar is attached to the cranium posteriorly through the hyomandibular. The upper articular portion of the *hyomandibular* is thick and rod-like and is covered with cartilage both dorsally and at the two ends. The anterior end fits into a notch in the sphenotic while the posterior tip gives articulation to the operculum. There is a thick ill ossified ventrally directed portion on either side of which the bone is very thin. There is a thin, large lamella developed on the inner side of this portion of the bone which forms the anterior wall of the accessory respiratory chamber. The hyomandibular branch of the VII nerve passes from the inner to the outer surface of the bone. The hyomandibular is separated from the symplectic by a thick piece of cartilage. The *symplectic* articulates anteriorly with the metapterygoid and ventrally with the quadrate. Posterior to the hyomandibular, symplectic and the quadrate is the long preopercular which has already been described.

7. *Mandibular Series* (Fig. 1).

The lower jaw consists of the *articulare* by which it articulates with the quadrate, a highly reduced, small *angulare* attached to the posteroventral corner of the articulare and a well-developed *dentary*. The two dentaries are connected with each other at the symphysis by means of ligament. The upper surface of the dentary is covered with sharp curved teeth. At the inner margin are few big canine teeth.

8. *Opercular Series* (Fig. 1).

There are all the three bones—operculum, suboperculum and interoperculum. They are large, thin bones. The *operculum* is articulated on the hyomandibular. The *suboperculum* is just behind the operculum. The *interoperculum* is connected by ligament internally to the epihyal and anteriorly to the angular.

Here I desire to express my gratitude to Prof. C. R. Narayan Rao, Dr. A. Subba Rao, Dr. B. K. Das and Prof. M. Sesha Iyengar for their kind help and encouragement. I am also thankful to my friend Mr. T. R. Doreswami for his help in the preparation of the drawings.

SUMMARY AND CONCLUSION.

1. Ectethmoids are separated completely by the supraethmoid and are pierced by the olfactory nerves.
2. Vomer is large and extends in front of the supraethmoid.
3. Orbitosphenoid is absent.
4. There is no cartilaginous or osseous interorbital septum.
5. The characteristic Y-shaped suprasphenoid is present.
6. There are two anterior myodomes and a posterior myodome. The latter is closed behind.
7. The trigemino-facialis chamber is present on the outer wall of the cranium.

8. There is a remarkable development of the prootics which form almost completely the outer wall of the auditory capsule, excluding the other otic bones. There are well developed auditory bullae.
9. The squamosopterotics and the epiotics are pushed out considerably and are excluded from the wall of the cranial cavity.
10. Opisthotic is very small and vestigeal.
11. Supraoccipital separates the parietals completely.
12. There are large subtemporal fossæ.
13. Foramen magnum is long and tunnel-like.
14. The exoccipitals are not separated by the supraoccipital and they do not meet below the foramen magnum, the floor of which is formed by the basioccipital.
15. Parasphenoid is long and possesses an oval patch of teeth.
16. The supratemporal is a loose, small, tubular bone.
17. The suborbital ring is complete with the suborbital branch of the senory canal. The nasals are fairly large extending in front of the supraethmoid.
18. Edentulous maxillaries which are excluded from the margin of the upper jaw and the flexible and fibrous nature of the outer ends of the premaxillaries.
19. There is a metapterygoid process which articulates with the cranium.
20. Hyomandibular has a broad inner lamella.

* * * * *

Though *Ophiocephalus striatus* exhibits certain primitive features it is highly specialised in several points of its cranial anatomy. The archaic characters are the inefficient ossification of certain parts of the skull, toothed vomer and parasphenoid and the superficial nature of the roofing bones. The parasphenoid teeth have already disappeared in *Ophiocephalus punctatus*. Among the specialised features are the complete separation of the parietals by the supraoccipital, the development of exoccipital condyles for the secondary articulation of the cranium with the vertebral column, the presence of well-developed trigemino-facialis chamber, the development of large shallow subtemporal fossæ, the enormous development of the prootics, the exclusion of other otic bones from the cranial cavity, absence of orbitosphenoid, the small vestigeal opisthotic and the edentulous nature of the maxillaries which do not form the margin of the upper jaw.

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ABBREVIATIONS.

ALIS.	Alisphenoid.
ANG.	Angulare.
ART.	Articulare.
ART. OP.	Articular surface for the operculum.
AU. BU.	Auditory bulla.
BO.	Basioccipital.
D.	Dentary.
ECP.	Ectopterygoid.
ECT.	Ectethmoid.
EPL.	Epiotic lamella.
EPO.	Epiotic.
EX.	Exoccipital.
EXC.	Exoccipital condyle.
fmg.	Foramen magnum.
FR.	Frontal.
HM.	Hyomandibular.
hypg.	Hypoglossal nerve foramen.
IOP.	Interoperculum.
LA.	Lacrymal.
MPT.	Metapterygoid.
MPT. PR.	Metapterygoid process.
MX.	Maxillary.
NA.	Nasal.
OP.	Operculum.
OPO.	Opisthotic.
p myo.	Posterior myodome.
PA.	Parietal.
PAL.	Palatine.
PMX.	Premaxillary.
po tf ch.	Posterior opening of the Trigemino-facialis chamber.
PREO.	Preoperculum.
PRO.	Prootic.
PS.	Parasphenoid.
Q.	Quadrate.
ras.	Recess for the anterior semicircular canal.

rs.	Recessus sacculus.
SBOR.	Suborbital.
sbt fo.	Subtemporal fossa.
SE.	Supraethmoid.
SO.	Supraoccipital.
SOB.	Suboperculum.
SOP.	Supraoccipital process.
SPH.	Sphenotic.
SQPTR.	Squamosopterotic.
SS.	Suprasphenoid.
SY.	Symplectic.
tf ch.	Trigemino-facialis chamber.
VO.	Vomer.
V & VII.	Trigemino-facialis foramen.
VIIh.	Hyomandibular branch of the VII nerve.
IX.	Glossopharyngeal foramen.
X.	Vagus foramen.

THE BEHAVIOUR OF THE GOLGI APPARATUS IN THE OOCYTES OF *EMYDA VITTATA* (KELAART).

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1. Introduction.
2. Previous Work.
3. Material and Methods.
4. Observations.
5. Discussion.
6. Summary.
7. Bibliography.

INTRODUCTION.

Recent cytological studies in both Vertebrates and Invertebrates have centred in the behaviour of the cytoplasmic inclusions during gametogenesis, especially the mitochondria and the Golgi apparatus. The behaviour of these inclusions presents a remarkable diversity even in forms closely related to each other, in the evolutionary series. Researches of King (1), Harvey (2), Nath (3) and others on Invertebrate oogenesis have demonstrated that the same cytoplasmic inclusion may not be responsible for any particular product of vitellogenesis. As shown by these authors, the albuminous yolk may arise in connection with either mitochondria or nucleoli ; while fatty yolk always arises in connection with the Golgi, Harvey has observed that the former arises *de novo* and the latter elaborates albuminous yolk in the eggs of *Carcinus mœnas*. Thus it is obvious that the behaviour of these inclusions is very arbitrary.

PREVIOUS WORK.

The literature on the oogenesis of Sauropsida alone is considerable and in many respects unique. Recent investigations from this group have established two distinct types of Golgi apparatus. Brambell (4) working on the oogenesis of the domestic fowl, *Gallus bankiva*, demonstrated for the first time two types of Golgi apparatus. Golgi type I, occurs in the oocyte proper in the region of the centrosphere and Golgi type II, exists in the cells of the follicular epithelium. He also observed for the first time an infiltration of the second type of Golgi from the follicle cells into the oocytes at various stages of oogenesis. Simultaneously with the findings of Brambell, D. R. Bhattacharya (5) published his results on the behaviour of cell inclusions in the oogenesis of *Testudo graeca* and *Uromastix hardwickii*, in both of which he finds that the Golgi bodies pass from the follicle cell in a manner similar to that described by Brambell in the fowl.

Since then, Bhattacharya and his pupils have examined a number of vertebrate eggs and have reported the infiltration of Golgi bodies. Bhattacharya and Krishna Behari Lal (6) in their contribution to reptilian oogenesis have found that the eggs of certain Indian tortoises, the Golgi forms a clearly polarised mass. During development the Golgi bodies are scattered about the cytoplasm and give rise to fatty yolk. The Golgi bodies found in the follicular epithelium migrate into the egg through the zona radiata.

P. R. Bhattacharya (7) studied the origin, growth and distribution of Golgi in the oogenesis of the house gecko and corroborated the findings of Bhattacharya and Lal.

In the fishes the Golgi bodies infiltrate through the zona radiata very early in development (8). In advanced oocytes a gradual diminution of extrusion of these bodies is found until finally it ceases and the zona radiata becomes thin and more opaque. In the later stages of oogenesis it is not possible to distinguish between the follicular and ovarian Golgi bodies.

The aim of this paper is to adduce additional evidence in support of the migration theory of the Golgi bodies from the follicular epithelium into the egg. An attempt is also made to indicate the manner and significance of this process.

In this connection I wish to express my gratitude to Mr. A. Narayana Rao for the very numerous acts of advice and assistance he has given in the course of this work.

MATERIAL AND METHODS.

The ovaries of the locally available mud tortoise, *Emyda vittata*, were dissected in normal saline solution and the following fixatives were employed. Bouin's picro-formol followed by Heidenhain's iron hæmatoxylin was employed for the study of the nucleus and nucleoli. Mannkopsch and Nassanov have been employed and the former, usually capricious in its results, has yielded very gratifying results (9). Ludford's modification of osmic methods has also given good results (10). Paraffin sections were cut 5 to 7 microns in thickness.

The ovaries are symmetrically disposed and placed far back in the abdomen. In the quiescent condition the ovaries are broad and variously folded. The surface of the ovary is raised up into rounded elevations and appear as so many white specks. These mark the position of the ova. Each ovary is attached by a peritoneal fold, mesoarium, to the sides of the vertebræ between the rectum and the oviduct. In the specimen measuring 14 cms. from snout to vent the ovary measured as follows: ovary 1.75 cms., width: anterior end 0.44 cms.; posterior end 0.5 cms.

OBSERVATIONS.

The early oocytes are provided with a cellular investment of a single layer of cells. The cells of the investment are very small with a nucleus corresponding to the size of the cell. The Golgi in the follicle cells is difficult to make out under ordinary magnifications. With the growth of the oocyte the cells of the follicular epithelium grow into prominent cells each having a large nucleus. Next to the follicular epithelium is the conspicuous envelope, zona radiata, pieced by numerous very fine canals which give it a characteristic radiate appearance. This envelope is generally very conspicuous in later oocytes.

In young oocytes the elements of the Golgi apparatus are in the form of rods, rings and crescents. They are all very heavily impregnated with osmic acid. Following Brambell, I propose to call this type of Golgi, present within the oocyte Golgi type I. The behaviour of these elements in oogenesis is very characteristic. The apparatus undergoes remarkable changes and a complete dispersal of these elements in all directions takes place.

Another set of elements which impregnates with silver and osmium but separate and distinct from similar bodies found in the oocytes can be distinctly seen in fairly advanced oocytes. These bodies are generally very close to the periphery and show a remarkable resemblance to the entire apparatus seen within each of the follicle cells surrounding the oocytes. These bodies I propose to call Golgi type II.

In very young oocytes the follicular lining consists of a single layer of cells. This second type of Golgi which presents a very characteristic network-like appearance is very small and impregnates less feebly with osmic than that of the cells surrounding the older oocytes (Fig. 1). At this stage the Golgi in the follicular cells is situated towards the pole of the cell away from the zona radiata. If the growth of the oocytes and follicle cells is followed the Golgi changes both in appearance and its topography. It undergoes marked hypertrophy

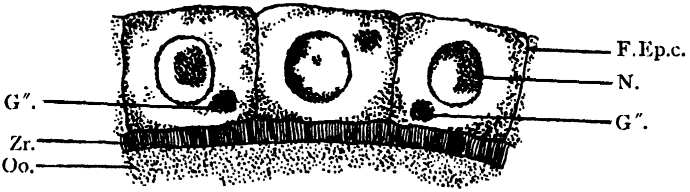

Fig. 1.

The follicle cells of a young oocyte showing the reticular Golgi type II.

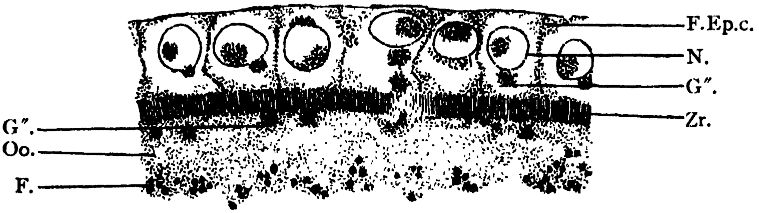

Fig. 2.

The Golgi type II undergoing hypertrophy and division in the follicle cells. The zona radiata is giving passage for the Golgi II.

(Fig. 2) and travels towards the pole of the nucleus of the follicular epithelium near the zona radiata. While these changes take place in the follicular epithelial cells one can easily observe deeply staining Golgi rods in the form of a network much smaller but nevertheless identical with the apparatus found within the follicle cells in the peripheral regions of the oocytes.

The marked similarity of these network-like bodies in the peripheral regions of the oocytes to those found in the follicular epithelium, their simultaneous appearance with the marked hypertrophy and division of the follicular Golgi, together with my observations of preparations which show part of the Golgi type II within the follicle cells and part in the oocyte through the zona radiata, very strongly suggest and corroborate the phenomenon of infiltration of these bodies from the follicle cells into the oocyte.

The migrated portions or parts of the Golgi type II are seen scattered round the periphery of the oocyte. The individual elements constituting the migrated portions of the Golgi type II are rod-shaped (Fig. 3). With the progress of oogenesis these structures break up and are distributed throughout the peripheral regions of the oocyte.

The infiltration of the Golgi from the follicular epithelium is observed only in late oocytes. The marked hypertrophy of the apparatus seems to be a necessary prelude for the migratory phenomenon. Actual transmission into the oocyte does not take place in isolated units as suggested by Behari Lal nor have I observed chains of migrating Golgi bodies such as has been reported by D. R. Bhattacharya in tortoises nor as described in birds and lizards by Datta and Das (11).

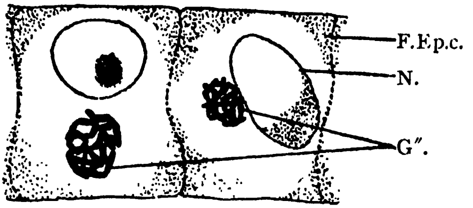

Fig. 3.

Follicle cells in which the rod-shaped reticulate Golgi type II are seen.

In my preparations the Golgi of the follicular epithelium, as suggested above, is aggregated towards one pole of the nucleus of the follicle cell and the migration is generally restricted to one area of the oocyte and does not take place throughout the follicular covering. The Mannkopsch preparations show that this particular region is intensely affected by osmic. Subsequent to their entry to the peripheral regions of the oocyte the network breaks up and the individual elements are distributed throughout the egg.

The changes in the Golgi bodies of the follicular epithelium become active and marked in certain stages and the onset of migration is noticed only in very late stages. An early oocyte with its surrounding layer of follicle cells shows hardly any trace of Golgi type II.

Regarding the manner of migration I have observed the widening out of the radial canals of the zona radiata through which the Golgi migrates into the oocyte. My preparations also show here and there a gradual thinning out of the zona radiata and one can observe in these areas the Golgi breaking through into the oocyte (Fig. 4). I have also found that the follicle cells in the neighbourhood of the region where the zona radiata has thinned out, are devoid of Golgi and dark bodies affected by osmic and identical in appearance to Golgi type II are found in corresponding regions of the oocyte. These facts suggest that the Golgi must have intruded into the oocytes through the thinned out zona radiata lead to a legitimate but tentative suggestion that under the influence of the Golgi the membrane thins out to allow the passage of the Golgi into the oocyte.

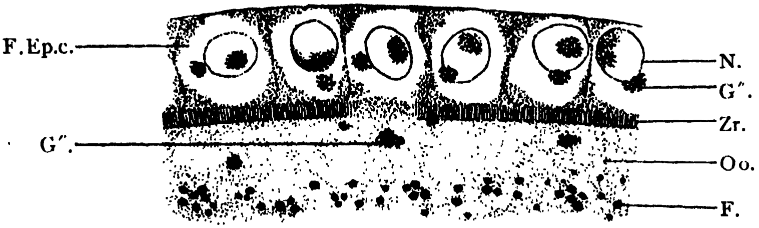

Fig. 4.

Shows the disintegration of the zona radiata and a part of the Golgi II in the follicle cells and part in the oocyte.

DISCUSSION.

An examination of the literature bearing on the phenomenon of migrations brings to light that this phenomenon is of very common occurrence in the majority of vertebrate eggs. Bhattacharya and his pupils (12) have demonstrated this fact in the Icthyopsida, reptiles and mammals while Brambell has shown that migration takes place in birds. It may be tentatively argued that this phenomenon must have a definite bearing on the metabolism of the egg. The eggs of all vertebrates below the mammalia are very large and the Golgi elements present in the oocyte before the migration from the follicular epithelium may not be sufficient to synthesise the requisite amount of the products of vitellogenesis. It is observed that subsequent to the infiltration there is no means of distinguishing between the elements of Golgi I and Golgi II either by their morphological appearance or by their function. Both sets of elements behave similarly and give rise to fatty yolk. It may be suggested that the migration of the follicular Golgi bodies into the oocyte may have the significance of augmenting the resources of the egg for vitellogenesis. But the infiltration of the Golgi in mammals whose eggs are small may not fit in with this suggestion but nevertheless must lend confirmatory evidence of the evolution of mammals from reptile-like ancestors with meroblastic eggs in which the migration has become an established fact. However the phenomenon of migration of Golgi elements from the follicular investment into the oocytes of mammals is not universal and has not been reported from studies of primitive primates (13), but this will not invalidate the view suggested here that in the present state of our knowledge we could only explain this phenomenon in the mammalian egg on the basis of recapitulation that the mammals recapitulate their reptilian ancestry in the ontogenetic phenomenon.

SUMMARY.

1. The oocytes of *Emyda vittata* show two types of Golgi bodies. Golgi type I is found in the oocyte and is juxtanuclear in position.

2. The follicle cells have a network-like Golgi very similar to the Golgi type II described by Brambell.

3. The Golgi apparatus of the follicular epithelium migrates into the oocyte without breaking up into smaller elements.

4. The migration is restricted to one area of the egg.

5. The migration commences only in very late stages of oogenesis.

6. The zona radiata which inhibits the free passage of Golgi undergoes certain changes ; the radial canals widen out and certain regions of the zona thin out.

7. The thinning out of the zona radiata is tentatively suggested to be due to an enzymic action of the Golgi bodies.

8. Both types of Golgi take active part in vitellogenesis and give rise to fatty yolk.

The behaviour of the Golgi apparatus in regard to their migration is very similar to that described by authors referred

to in the earlier part of the paper. My observations show that the migration is restricted to certain stages of oogenesis and to particular areas of follicular epithelium. The form and manner of migration resemble to a very large extent a similar phenomenon described by Brambell. In their subsequent behaviour the follicular Golgi elements are even distributed throughout the oocyte and structurally and functionally it is not possible to distinguish the two types of Golgi in the oocytes of the later stages of oogenesis.

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KEY TO LETTERING.

F.Ep.C.	..	Follicular epithelial cells.
F.	..	Fat bodies.
N.	..	Nucleus.
G″.	..	Golgi type II.
Oo.	..	Oocyte.
Zr.	..	Zona radiata.

4:6 DIHYDROXYISOPHTHALIC ACID.

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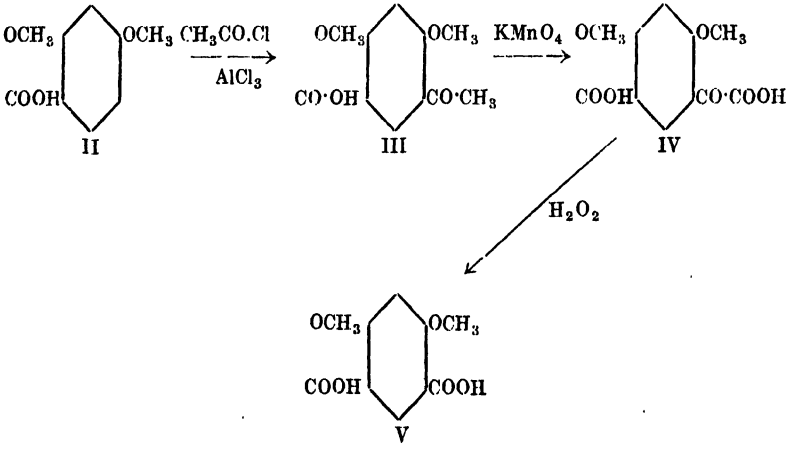
4:6 *Dihydroxyisophthalic acid* I was required for establishing the nature of one of the oxidation products of *Psoralen* $C_{11}H_6O_3$, isolated from *Psoralea Corylifolia* seeds (Jois, Manjunath and Venkata Rao, *J. Ind. Chem. Soc.*, 1933, **10**, 45). Reference to literature showed that it was known only in the form of its dimethyl and diethyl ethers (Eykman, Bergema and Henrard, Beilstein's *Handbuch der Organischen Chemie*, 4th ed., 1927, Vol. X, p. 554). Consequently experiments were undertaken to obtain the free acid to study some of its characteristics.

Attempts were made to carry out Wurtz synthesis with the *ethyl ester of* 2:4 *dimethoxy*-5 *bromobenzoic acid* and chlororformic ester, but without success. It was also found that the above ester would not form the Grignard compound.

4:6 Dimethoxyisophthalic acid V was then synthesised starting with the dimethyl ether of β-resorcylic acid II through the following stages:



Demethylation was effected by heating the substance with redistilled hydriodic acid (d., 1.7) in the usual manner. The identity of I thus obtained was established by the methylation of its dimethyl ester when the ester of V was formed.

Experimental.

Ethyl ester of 2 : 4 *dimethoxy*-5 *bromobenzoic acid* :—Colourless crystalline powder from dilute alcohol, m.p. 88.5° (Found Br, 27.8 ; $C_{11}H_{13}O_4Br$. requires Br, 27.7 per cent.).

Dimethyl and diethyl esters of V :—Dimethoxy resorcylic acid II was converted into resacetophenone carboxylic acid III according to the method of Liebermann and Lindenbaum (*Ber.*, 1908, **41**, 1613). Oxidation to 3 carboxy 4 : 6 dimethoxyphenylglyoxylic acid IV (Eykman and others, *loc. cit.*, p. 1038) was effected by alkaline permanganate solution (yield 50 per cent.). Conversion to V was accomplished by treatment with acidified permanganate. The yield was nearly quantitative when 1 g. of IV was dissolved in 20 c.c. of 5 per cent. NaOH, a slight excess of perhydrol added and warmed on a water-bath for an hour. M.p. of V, 266°.

Dimethyl ester : Crystalline powder from dilute alcohol, m.p. 150° (Found C, 56.8 ; H, 5.5 ; $C_{12}H_{14}O_6$ requires C, 59.6 ; H, 6.4 per cent.).

Diethyl ester : Rectangular plates from dilute alcohol, m.p. 83.5° (Found C, 59.3 ; H, 6.5 ; $C_{14}H_{18}O_6$ requires C, 59.6 ; H, 6.4 per cent.).

4 : 6 *Dihydroxyisophthalic acid and its esters* :—The demethylation of V was effected by suspending it (1 g.) in freshly distilled hydriodic acid (d., 1.7 ; 10 c.c.) and heating it at 130° for 15 minutes. It was then filtered, washed with water, crystallised from dilute alcohol and finally from water (yield, 60 per cent.).

Rectangular plates, m.p. 306° (Found C, 48.5 ; H, 3.2 ; $C_8H_6O_6$ requires C, 48.5 ; H, 3.1 per cent.).

Dimethyl ester : Colourless rectangular prisms from benzene, m.p. 147° (Found C, 53.3 ; H, 4.4 ; $C_{10}H_{10}O_6$ requires C, 53.1 ; H, 4.5 per cent.).

Diethyl ester : Colourless rectangular prisms from benzene, m.p. 141° (Found C, 56.6 ; H, 5.4 ; $C_{12}H_{14}O_6$ requires C, 56.7 ; H, 5.5 per cent.).

Methylation of I with methyl sulphate and alkali gave only the dimethyl ester, and no satisfactory result was obtained by treating the dimethyl and diethyl esters with diazomethane. The dimethyl ester dissolved in benzene was treated with methyl iodide and silver oxide. After refluxing for six hours benzene was distilled off and the residue extracted with ether. The ethereal extract was shaken up with very dilute alkali to remove unchanged phenolic ester. On evaporating off the ether, the residue on purification was found to be identical with the dimethyl ester of V.

ON A NEW FOSSIL HYÆNA.

By C. R. Narayan Rao, M.A.
(*Department of Zoology, University of Mysore, Bangalore.*)

The materials which form the subject-matter of this paper were collected in the Ariyalur area, Trichinopoly district, some years ago and for several reasons they could not be dealt with till now. During my visit to Calcutta in 1930 I was enabled through the courtesy of Dr. G. E. Pilgrim to compare my specimens with the collection of fossil Hyænas in the Geological Section of the Indian Museum and I take this opportunity of expressing my gratitude to him for examining my material and for drawing my attention to the several papers on the subject. After going through the relevant literature and comparing with known forms, I have come to the conclusion that the Ariyalur finds really include two species of Hyæna, one of which is new to science and which I have great pleasure in associating with the name of Dr. Pilgrim and the other represents the species which Lydekker has already described as *Hyœna crocuta* (1) from a partially-worn left lower carnassial tooth obtained from Kurnool.

Writing about the Ariyalur specimens Dr. Pilgrim (2) observes that "early in 1930 Professor Narayana Rao of the Mysore University called my attention to two fragments of the palate of a Hyæna, which a party working under his direction had discovered in an almost denuded alluvial deposit in the Trichinopoly district of Madras. These fragments are the left maxilla containing P^2 P^4 and the alveoli of P^1 & M^1 and the right maxilla containing the canine P^1 & P^2. These are as yet undescribed but these obviously differ greatly from the living *Hyœna hyœna* and are referable to the genus *Crocuta*. Their precise affinities will no doubt be made known by Professor C. R. Narayana Rao in a paper which he has in contemplation."

"Since the age of the deposit is probably approximately the same as that of the Billa Surgam Cave fauna (Kurnool), it seems likely that the M_1 from the latter deposit, which was described and figured by Lydekker (1886, *Pal. Ind.* (10), Vol.

IV, Pl. VII, Figs. 13, 13*a*) under the name of *Hyæna crocuta* may belong to the present species."

According to Lydekker the age of the Kurnool Cave Deposits is not newer than the Pleistocene and the fauna is assigned to the latter part of that period and is considered therefore as more recent than that of the Nurbuda beds. Describing the Cuddalore series Wadia (3) mentions that a great part of the Cuddalore sandstone is believed to be of Miocene age, but parts of it may be of newer horizons. These deposits rest unconformably everywhere on the older rocks of various ages, "in one instance overlying the Ariyalur stage of the Trichinopoly Cretaceous". From the evidence furnished by the evolutionary stage of the Siwalik fauna, the age of this system is believed to extend from the middle Miocene to the upper Pliocene, and if Cuddalore deposits are definitely of the Miocene age, it is probable that they represent a parallel series of deposits approximately contemporaneous with the Siwaliks. This view is tenable provided the Cuddalore sandstones can be shown to contain mammalian and other vertebrate fossil remains having a strong Siwalik facies. It is true that several disarticulated and broken fragments of bones of Carnivora and Ungulata togther with their teeth have been obtained from Ariyalur and among those which can be identified, a few may ultimately be found to possess affinity with the Siwalik fauna though a greater portion of these remains are referable to the newer pleistocene period. Perhaps a more intensive collection of the fossil remains from the Ariyalur area will have to be made and studied, and some will have to be obtained together with the rock matrix, before a final decision of the age of the overlying deposits of the peninsular cretaceous rocks could be reached. But it seems certain that the evidence available at present is far too meagre to enable one to refer the Ariyalur mammalian fossils to the Cuddalore sandstones occurring in this area or to the pleistocene beds which also occur in certain isolated tracts. The difficulty is due to the fact that most of our collections are surface pickings and till now no mammalian fossils have been reported definitely from Cuddalore sandstones and I should hesitate to accept the theory of Dr. Pilgrim that the age of the mammalian fossil-bearing rocks of Ariyalur is probably approximately that of Billa Surgam Cave of Kurnool.

In commenting on the Ariyalur find and the lower molar tooth from Kurnool, Dr. Pilgrim suggests tentatively that they both might belong to the same species and if Lydekker's identification of the Kurnool tooth is correct, then both these forms must belong to the living species *Crocuta crocuta*, fossil remains of which are widely known from Pleistocene beds of Europe. In treating the Kurnool form as synonymous with the Ariyalur fossil Dr. Pilgrim makes no suggestion that the latter is a known form and the permission he has given to associate his name with this find is a definite indication that he considers it to be new, a conclusion at which I had arrived after examining the rich collection of fossil remains of Hyænas belonging to the Indian Geological Survey. In 1931 two canines of Hyæna were obtained from Ariyalur which differ from each other, one of them which is broken is slightly larger than the specimen examined by Dr. Pilgrim and the other which is entire, differs from the latter in almost every detail. The larger broken specimen presumably belongs to the Ariyalur species which is considered to be new, and the more slender one I assign to the Kurnool form which is different and which I refer to *Crocuta crocuta*. According to this view, South India was inhabited by two species of *Crocuta* in addition to *Hyæna hyæna* and while one species of the former genus has become totally extinct, the other *Crocuta crocuta* which enjoyed a very wide distribution, is still found living in Africa.

CROCUTA PILGRIMINA n. sp.

The right maxilla represented in the collection is a small triangular piece of bone about 1.7 in. high and 1.3 in. long on the external surface. The socket for the canine is partially broken, thus exposing the greater part of the entire root of this tooth. The premaxilla together with the incisors is absent. The maxillo-palatine shelf is present in the form of a ridge running along the inner border of the maxilla, on this surface the bone measures 2 in. long and 1.6 in. in height. Above the palatine ridge, the maxilla is worn out into a deep oval excavation. The canine is robust, large, almost flat on the outer and inner surfaces. It measures along the anterior curve 76 mm. and is nearly elliptical in cross section. Thickness 13 mm., width at base of crown 22.5 mm., root pointed. The lateral compression of the canine is marked. The tip of crown slightly worn. P^1 is present though small; the surface is worn, the paracone more prominent than the other cusps. The proto- and metacones are less conspicuous, height merely equals the length and thickness is 7 mm. P^2 well developed. Probably on account of the greater wearing of the cusps, the tooth has a quadrilateral appearance; still the prominent nature of the middle cone is obvious. The protocone and metacone are weak and lie on the inner side of the tooth. The length of this tooth is 16 mm., height of the crown 10 mm. and thickness 11 mm.

The left maxilla bears P^2, P^3 and P^4 and P^1 is broken to the very base. Close to P^1 is the wide alveolus of the canine which has dropped. P^2 and P^3 are constructed almost in the same fashion. The middle cone is prominent and the protocones and the metacones are poorly developed in both. P^3 is 15 mm. long, 9 mm. high and 11 mm. in thickness. In the process of cleaning it has sustained a slight damage, but at the time of discovery, it was noted that the anterior and posterior cusps though not well developed, were present on the inner aspect of the tooth. P^3 is robust, distinctly conical, the paracone powerfully developed and of great height, the tip is blunt; 21 mm. long, 17 mm. high and 14 mm. in thickness. There is a fairly well marked cingulum, the protocone and metacone are poorly formed, the posterior cusp is better marked and the posterior is almost in a line with the main cusp and the anterior possibly occupied the more inner aspect of the tooth. The inner surface of the tooth between the anterior and posterior cusps is distinctly flat and the outer nearly flat. The cingular shelf does not extend on the inner aspect of the tooth. In the X-ray photograph, no separate root is therefore made out. The elements of P^3 diverge markedly from those of *Crocuta crocuta* and *Hyæna hyæna*. P^4 is longer (37.5 mm.) than the united lengths of P^2 and P^3 (15 *plus* 21=36 mm.). All the cusps are practically in the same line and the tooth is certainly more internally situated than P^3 which is distinctly external in relation to it. The protocone is poorly developed, somewhat low and adjacent to the base of the parastyle, having a distinct root on which it stands. At the antero-internal edge the inner tubercle is fairly prominently developed. The metacone is much longer (16.5 mm.) than the paracone (13.5 mm.) but considerably lower. The portion of the maxilla bearing M series is wanting and so they are unknown.

The broken canine figured separately resembles the entire tooth of *C. pilgrimina.*

Locality.—Shendurai, Ariyalur, Trichinopoly district.

Horizon.—Possibly Cuddalore sandstone.

CROCUTA CROCUTA ERXL.

1886, *Hyæna crocuta* Erxl. Lydekker, *Pal. Ind.* (10), IV, p. 30.

Lydekker in dealing with the fossil collections obtained from the cave deposits of Kurnool, has described a partially worn left lower carnassial tooth of Hyæna which he identified as that belonging to *Hyæna crocuta* (*Crocuta crocuta*). I have examined this specimen preserved in the Indian Museum collection and have noted its resemblance to the tooth of the living spotted species of Hyæna met with in Africa. There is a great deal of divergence between this tooth and the corresponding upper carnassial of the left maxilla of *Crocuta pilgrimina* and for purposes of comparison, I have reproduced Lydekker's figure. Further comparisons of the Ariyalur specimen with the European fossils of *Crocuta crocuta* will reveal several other points of difference.

Lydekker has made a short note on a canine represented in the Kurnool collection and on account of its imperfect nature, has written that it "may not improbably be referred to the present species."

In our collection there is a canine, belonging to the maxilla which undoubtedly is referable to *Crocuta crocuta* and differs from that of *Crocuta pilgrimina* in several important particulars. I have given a representation of this tooth. It is more slender and less arched. The Ariyalur single canine tooth measures 72 mm. along the anterior convex border, and 18 mm. at its greatest width.

This canine together with the carnassial tooth from Kurnool establishes that in South India towards the pleistocene period there lived more than one species of Crocuta of which *C. pilgrimina* is by far the larger.

Locality.—Shendurai, Ariyalur, Trichinopoly district.

Horizon.—Probably Cuddalore sandstone.

The types of the two species are preserved in the Museum collection of the University of Mysore.

REFERENCES.

1. Lydekker .. 1886, *Pal. Ind.* (10), IV, p. 30, Pl. VII, Figs. 13 & 13*a*.
2. Pilgrim, G. E. .. 1932, *Pal. Ind.*, N. S., Vol. XVIII, p. 153.
3. Wadia, D. N. .. *Geology of India*, 1919, p. 209, Macmillan & Co.

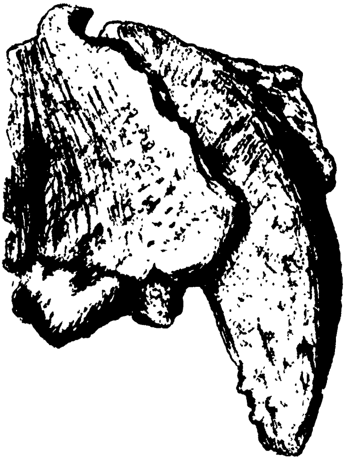


Fig. 1.

Right Maxilla of *Crocuta pilgrimina.*
Outer view showing canine P^1 P^2.

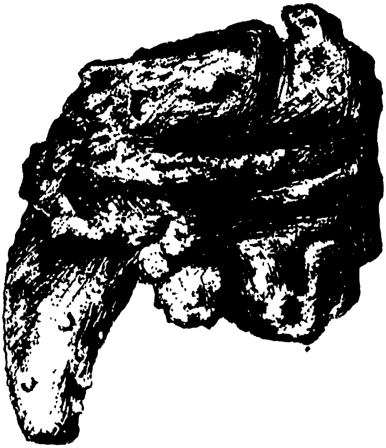


Fig. 1 a.

Inner View.

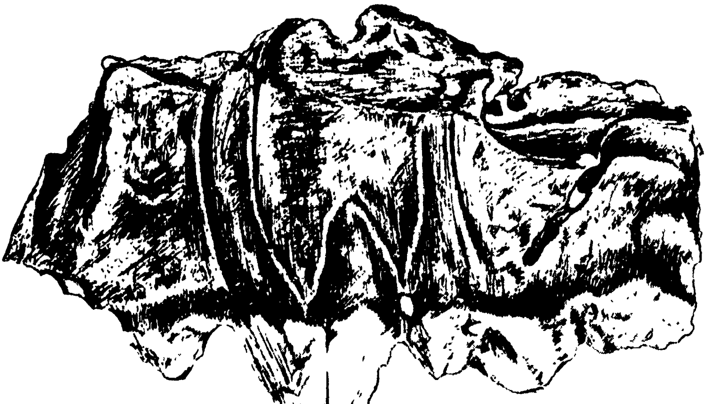


Fig. 2.

Left Maxilla. Outer view showing the alveolus for canine and broken P^1.

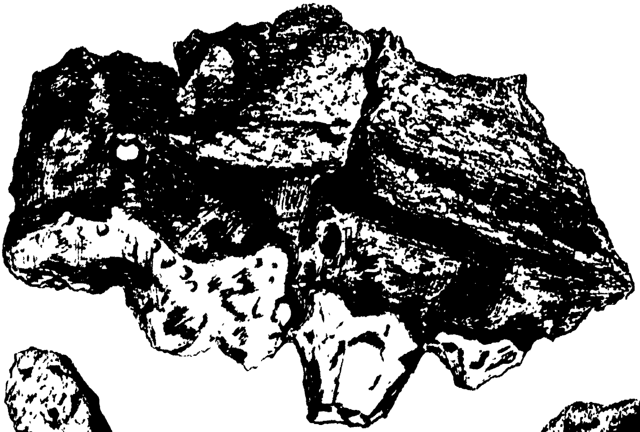


Fig. 2 a.

Inner View.

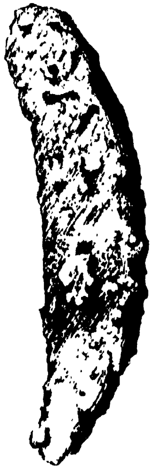


Fig. 3.

Canine of *Crocuta crocuta.*

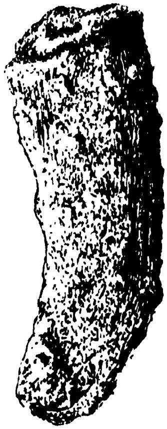


Fig. 4.

Broken Canine of *Crocuta pilgrimina.*

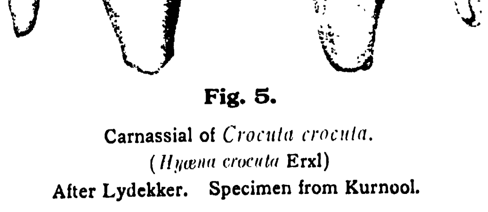


Fig. 5.

Carnassial of *Crocuta crocuta.*

(*Hyæna crocuta* Erxl)

After Lydekker. Specimen from Kurnool.

ON SOME STONE IMPLEMENTS FROM SOUTH INDIA—II.

By K. Sripada Rao, B.Sc.
(*Central College, Bangalore.*)

Amongst the relics of the Stone Age in Southern India we have a number of stone implements comparable to the Chellean and Acheulean cultures of Europe but representatives similar to those of the Mousterian industry are rarely met with. In a paper contributed to the Indian Science Congress (1930) and subsequently published in this Journal,* I have described some interesting types similar to those of the late Acheulean stage of Europe. It is the object of this paper to draw attention to a few more implements showing a very close resemblance to the Mousterian types of the Continent.

The chief characteristic of the Mousterian tool is an economy of labour. "Unlike Lower Palæolithic Man, Mousterian Man preferred to trim flakes taken off large nodules of flint for his tools, rather than fashion the cores into implements, as had been the habit of the older civilizations. It should be carefully borne in mind that this is by no means invariable; there are implements made from flakes in Chellean times, and implements made from cores in Mousterian times, but as is obvious the making of implements from a large flake is a great saving of time, and as the Mousterian had learnt to strike off these larger flakes we find the great majority of the implements made from them."†

In accordance with the characteristics of the Mousterian period the implements here described are fashioned out of flakes and are distinguished from the tools of the preceding stages by the peculiarity that they are chipped on one side of the flake only, unlike the Chellean and the Acheulean implements which are trimmed over the whole surface on both the sides. The bulb of percussion almost invariably found on the inner side of flint flakes is conspicuously absent from the quartzite flakes of which the implements described are fashioned—this is probably a result of the difference in fracture between the two materials. The implements were collected along with a number of others during the various geological excursions of the Central College, Bangalore. They consist of a typical Mousterian point from the south of Vilaungudy in the Trichinopoly district made of a brownish-looking cherty material: a borer and an arrow-head made of quartzite from the Alicoor Hills near Nagalapuram, and a *coup de poing* and a lance head made of quartzite from Biligere in the Tiptur taluk, Mysore.

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* *Half-Yearly Journal of the Mysore University*, Vol. IV, No. 2, p. 202.

† M. C. Burkitt, *Prehistory*, p. 91.

On a typological basis all these implements may be considered to belong to a culture similar to the Mousterian of the Continent, since similar environments engender to a very large extent like requirements and consequently the production of similar types of tools, but no similarity in age is necessarily implied.

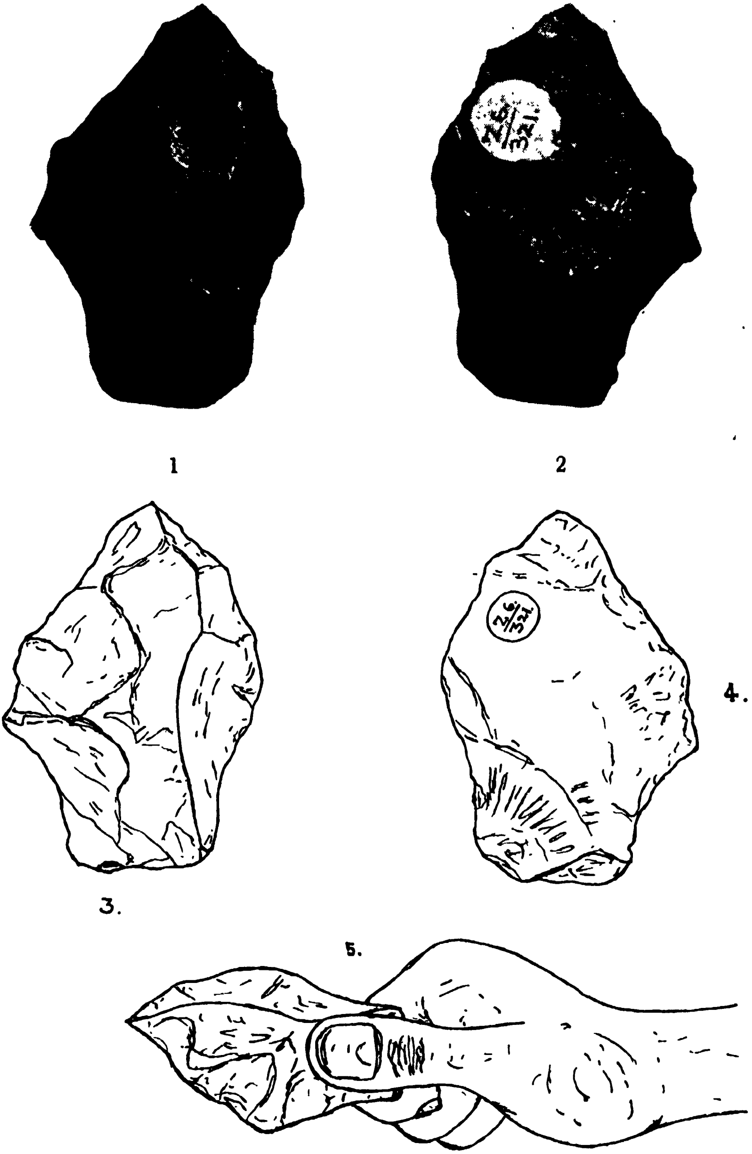
The descriptions of the implements are accompanied by photographs and sketches. The words "inner" and "outer" which are frequently used in describing the specimens are to be understood as referring to the position of the flake when in its bed on the nodule to which it belongs.

A MOUSTERIAN POINT FROM THE TRICHINOPOLY DISTRICT.

(No. Z. 6/321. Plate I, Figs. 1-5.)

This specimen was picked up nearly two miles south of Vilaungudy in the Trichinopoly district. It is roughly lanceolate in shape and is fashioned out of a brownish-looking flinty chert. The specimen measures 2.9 inches in length, 1.8 inches in width, and 0.75 inches in thickness and weighs 2¾ ounces. The inner side is uneven and devoid of any signs of fashioning, but the outer is fashioned by a number of individual flakings. There is a sort of an S-shaped ridge going from the pointed end to the opposite butt end formed as a result of the meeting of the flakings on either side of the specimen. One end is finely pointed and very sharp and the opposite end is obliquely truncated and nearly an inch in length. The two sides of the implement are sharp as a result of the inclined flakings meeting the inner side in a fine edge. Even the ridge is fairly sharp and it is disposed not in the median line but a little to one side. The longitudinal ridge in conjunction with the two sharp sides of the implement, give the point a sufficient keenness. In cross section it is triangular in appearance, the three corners

PLATE I.



A Mousterian Point from the Trichinopoly District.

of the triangle representing the three cutting edges of the implement. Since the butt end does not present any sharp edges or points, a convenient grasp of the implement is possible. Other similar implements have been found in the same locality as well as near Biligere in the Tiptur taluk, Mysore (Z. 6/292, z.6/312).

The implement here described is very similar to the one known as the 'Pointe' or the 'hand point' which is a characteristic tool of the Mousterian culture of Europe. It is spear-headed in shape and chipped on one side only, with a sharp apical point. The base of the instrument is as the detaching blow left it, with an incipient bulb of percussion on the inner surface. It was probably used as a Javelin or Spear head or as MM. Bouyssonie and Bardon suggest it may have been used for splitting bones in order to get at the marrow.* According to De Mortillet's theory of the manner of using the Mousterian Point, which was held in the hand and not shafted, I have given a drawing in Plate I, Fig. 5 for which I am indebted to Prof. Osborn's *Men of the Old Stone Age*.†

The specimen described shows a close resemblance to the one figured in Osborn's *Men of the Old Stone Age* which is from the Crimea, in Southern Russia.‡

A COMBINED BURIN AND RACLOIR FROM ALICOOR.

(No. Z. 6/147. Plate II. Figs. 1-5.)

The implement was found at the foot of the Alicoor Hills, north-east of Nagalapuram in the Arcot district. This area has afforded a number of very good Lower Palæolithic implements made out of quartzites of various colours like pink, red, grey and yellowish. The abundance of these implements in this area suggest that this site may have been a palæolithic station.

The implement in question is fashioned out of a greyish brown fine grained quartzite and weighs 2¼ ounces. It is beak-shaped in form and measures 2.9 inches in length, 2.1 inches in width and 0.6 inches in thickness. The inner surface is very slightly concave and does not show any signs of retouch. The outer surface is covered by five well-defined

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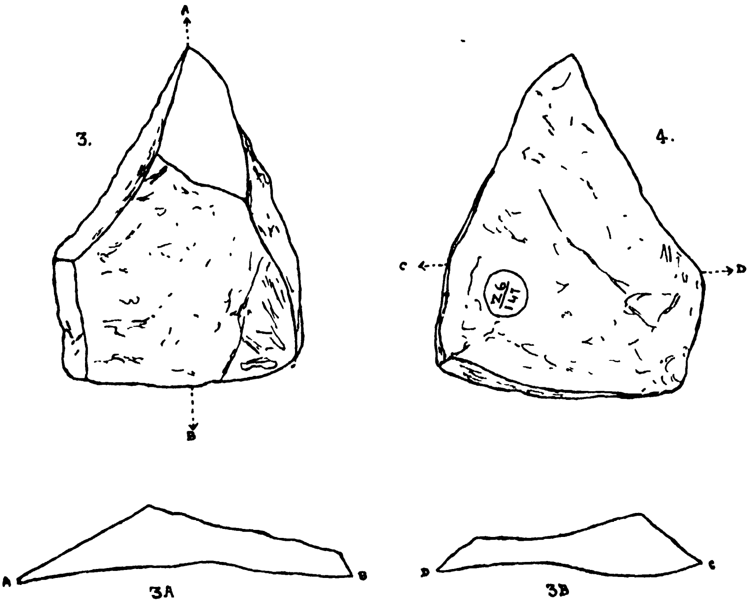
* R. A. S. Macalister, *Text-Book of European Archæology*, Vol. I, p. 320.

† H. F. Osborn, *Men of the Old Stone Age*, p. 251, Fig. 129 (100).

‡ *Ibid.*, p. 251, Fig. 129 (103-104).

PLATE II.



A Combined Burin and Racloir from the Alicoor Hills.

flakings four of which are elongated quadrilaterals in shape and disposed marginally on the four sides of the tool, two of the largest meeting to give rise to the pointed end of the specimen. The lengths of the four sides are 2.1 inches, 3.0 inches, 2.0 inches and 1.1 inch. The fifth and the biggest of the chipped surfaces is pentagonal in outline (nearly 1.9 inches broad) and is centrally placed near the butt end of the tool. In continuation of this flaked surface there is a triangular portion which also looks like a chipped face but which is really the original surface of the quartzite. The pointed end of the implement is triangular in cross section, the three angles being the main sharp utilization edges. The butt end is obliquely truncated by a long and narrow rectangular facet, which lies comfortably in the hand without causing any hurt while using. The angle made at the pointed end by the two elongated flake scars is about 55 degrees. The sharp and pointed end certainly suggests a burin or borer ; and since one of the four sides has got a sharp edge it may also have been used as a sort of a side scraper or ' racloir '. The implement described has a very close resemblance to some beaked gravers or burins figured in Burkitt's " Prehistory ",* and has many points in common with a borer from Yorkshire Wolds figured in Evans' "Ancient Stone Implements of Great Britain,"† where he says : " It is formed from a flat splinter of flint, and shows the natural crust of the stone at the broad end. At the other, each edge has been chipped away from the flat face, so as to reduce it by a rapid curve on each side to a somewhat tapering blade with a sharp point." The specimen described differs from the one from the Yorkshire Wolds in having the point produced as a result of the chipping away from the flat face, so as to reduce it by a straight line instead of by a rapid curve on each side. " A borer of this kind makes a very true hole as whether turned round continuously or alternately in each direction, it acts as a half-round broach or rimer, enlarging the mouth of the hole all the time it is being deepened by the drilling of the point. The broad base of the flake serves as a handle by which to turn the tool........A borer of this kind has been experimentally tried and found efficient for drilling a hole in jet.‡ The burins and scrapers are the commonest tools of the Mousterian period.

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* M. C. Burkitt, *Prehistory*, p. 340, Part IV, Figs. 14 and 15.

† J. W. Evans, *Ancient Stone Implements of Great Britain*, p. 322, Fig. 227.

‡ *Ibid.*, p. 322.

AN ARROW-HEAD FROM THE ALICOOR HILLS.

(Z. 6/161. Plate III. Figs. 1-5.)

This implement was also picked up in a nulla course at the foot of the Alicoor Hills, near Nagalapuram in the Arcot district. It is made out of a greyish-looking quartzite stained dark reddish brown at the pointed end and weighs ¾ of an ounce. In shape it is like a swallow tail, with incipient forking at the end opposite the pointed end of the tool. The length of the specimen is 2.6", width 1.1" and thickness ½ an inch. The inner surface is concave and curved and devoid of chipped or flaked surfaces. The outer surface, on the other hand, is covered by four distinct flakings two of which are laterally disposed and elongated trapezohedrons in shape, meeting in a central longitudinal sharp, straight edge nearly 1.4 inches in length. The other two chipped surfaces are triangular in shape and placed one at each end of the implement. The longer of the two trapezohedral flaked surfaces together with one of the triangular ones gives rise to a sharp and pointed end, like that of an arrow, while the other triangular facet is placed opposite and has its base partially incurved giving it a sort of a swallow tail appearance. The inner surface of the tool presents a trapezohedral outline with the sides measuring 2.6", 1.6", 1.3", and 1.1". This surface in conjunction with the outer chipped faces gives the implement a sharpness on all the four sides. The cutting edges are formed by the surfaces meeting at an average angle of 37 degrees. The point of the specimen is not quite sharp, probably a result of use, or it may have been subsequently blunted by natural agencies. The implement is triangular in section across the middle, the three angles being the sharp cutting edges of the instrument. The shape of the tool, with its pointed end and sharp cutting edges, obviously suggests an arrow-head which has to be used with a small shaft. The probable way of shafting the arrow-head is suggested in Fig. 5, Plate III. This method of shafting is very commonly made use of as it does not involve any elaborate requirements.*

The implement described resembles the one figured in Evans' "Ancient Stone Implements from Great Britain"† and Burkitt's‡ "Prehistory", although these are supposed

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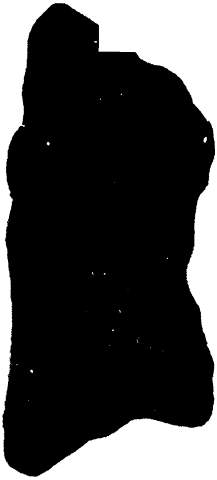
* J. W. Evans, *Ancient Stone Implements of Great Britain*, pp. 408, 409, Figs. 343, 345.

† *Ibid*, p. 325, Fig. 232 F. (From the Vindhya Hills).

‡ M. C. Burkitt, *Prehistory*, p. 336, Plate II, Figs. 9 and 10.

PLATE III.



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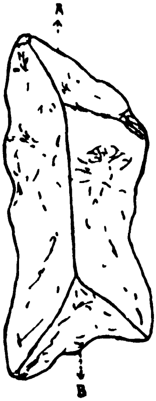

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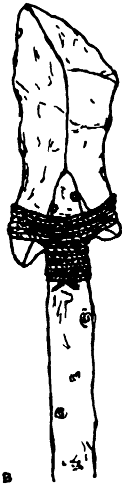

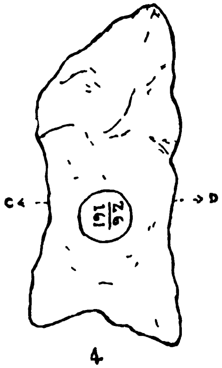

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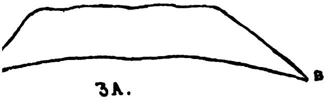
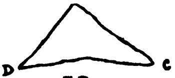


3A.



3B.

An Arrow-Head from the Alicoor Hills.

to be either end scrapers or burins. Those referred to by Dr. Evans in his book are, he says, "found in some abundance on the Vindhya Hills and the Banda district, India."*

A LANCE-HEAD FROM KIBBANHALLI, MYSORE.

(Z. 6/148. Plate IV. Figs. 1-5.)

This implement is lanceolate in shape (leaf-shaped), with a distinct point and tang or stem. It is fashioned from a brownish-looking quartzite and weighs nearly 4¾ ounces. This was found in a small nulla course at the foot of a quartzite hill, in Kibbanhalli, Tiptur taluk, Mysore. As a result of water action the whole specimen is smoothened and the boundaries between the different chipped surfaces are not very prominently seen. The dimensions of the tool are:—Length 4.0″, width 2.6″ and thickness ¾ of an inch.

The inner surface is concave and unfashioned as in the majority of the Mousterian implements. The outer surface on the other hand is composed of a number of flaked faces, the biggest and the most prominent of which is longitudinally disposed in the median line from point to the tang or stem. The marginal flakings are smaller and closely set but as a result of water action the boundaries between the individual facets are worn out and a bit hazy. The sides of the implement are sharp and the end opposite the lance point is truncated by an obliquely flaked face 0.9 inches in length. There is a fairly distinct stem or tang nearly ¾ of an inch in length, opposite the pointed end. The point of the lance seems to have been blunted by use. The leaf-like shape with the sharp edges and point and the stem or tang unquestionably suggest a lance-head intended for hafting. The most probable way in which it may have been hafted for use is suggested in Fig. 5 in Plate IV.

The implement described has a very close resemblance to the one figured in Osborn's *Men of the Old Stone Age*,† and another from Sollas' *Ancient Hunters*.‡ Also Fig. XIV (1) and (2) in Burkitt's *South Africa's Past in Stone and Paint*.||

Other implements similar to the one described are found in the same area (Kibbanhalli) and also in Vilaungudy in the

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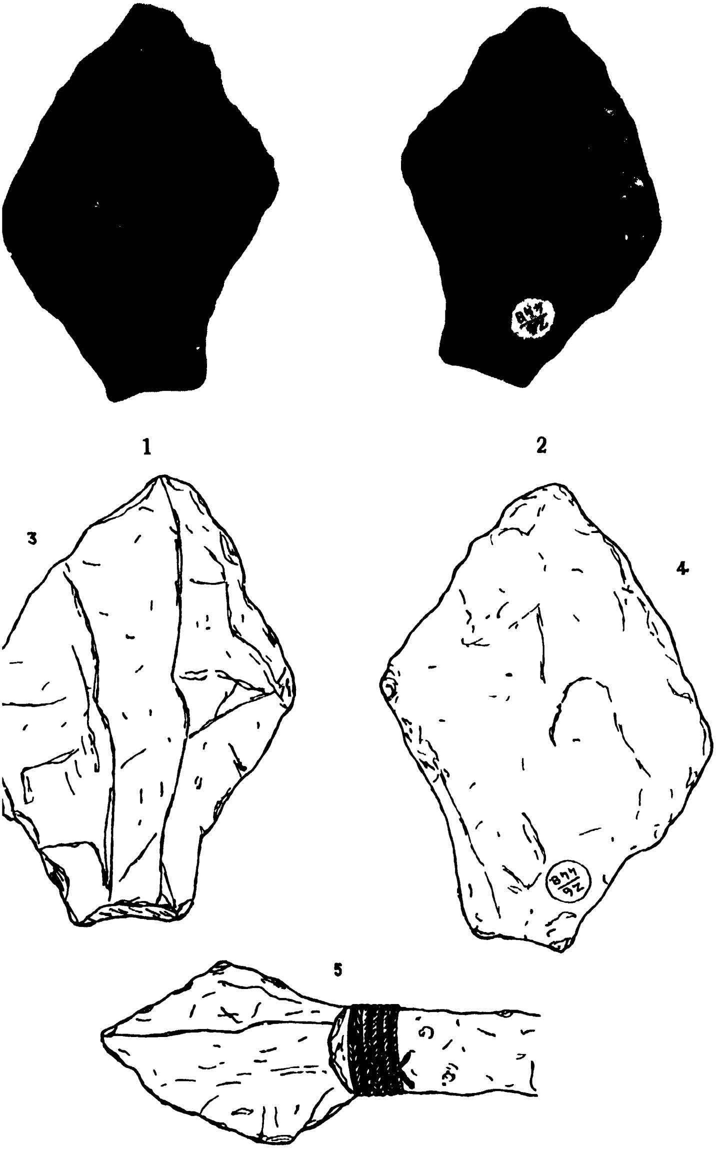
* J. W. Evans, *Ancient Stone Implements of Great Britain*, p. 232.

† H. F. Osborn, *Men of the Old Stone Age*, p. 15, Fig. 4.

‡ Sollas, *Ancient Hunters*, p. 204, Fig. 8.

|| M. C. Burkitt, *South Africa's Past in Stone and Paint*, p. 85, Fig. XIV, 1-2.

PLATE IV.



A Lance-Head from Kibbanhalli, Mysore.

Trichinopoly district (Z. 6/729, 321). "Such an identity of form at places geographically so remote does not imply any actual communication between those who made the tools, but merely shows that some of the requirements of daily life, and the means at command for fulfilling them being the same, tools of the same character have been developed, irrespective of time or space."*

A MOUSTERIAN COUP DE POING FROM KIBBANHALLI.

(No. Z. 6/449. Plate V. Figs. 1-4.)

In the Mousterian period we find that the coup,de poing diminishes in importance and is very poorly represented but it does persist to the end of the Mousterian stage, although they can scarcely be said to rival the neat finish of the Acheulean coups de poing.

Like the vast majority of the Mousterian implements this is also made from a flake fashioned only on one side. It is pear-shaped in form and is fashioned out of stained fuchsite quartzite. This was found near Kibbanhalli in the Tiptur taluk, Mysore, and weighs 5¼ ounces. The peculiarity of the implement lies in the fact that it is prepared from a flake and fashioned on one side only instead of on both the sides as in the Acheulean times. It measures 4.3″ in length, 3.2″ in width and ¾ of an inch in thickness.

The inner surface is unflaked whereas the outer one is fashioned by a number of big and broad flaked faces, the inner margins of which meet to give rise to an undulating median ridge or keel, running from the point to the butt. The sides are sharp as a result of marginal retouching. The pointed end is fractured probably by natural agencies.

It is quite probable that this tool may also have served the purpose of a 'hand-point' in addition to its being used as a coup de poing.

The specimen described has many points in common with the one figured in Sollas'† belonging to the Lower Mousterian although the finish is not so neat, and the flaking is on one side only. The implement has a remarkable resemblance to a Mousterian Point figured in Passemard's "Les Stations Palæolithiques du pays Basque."‡

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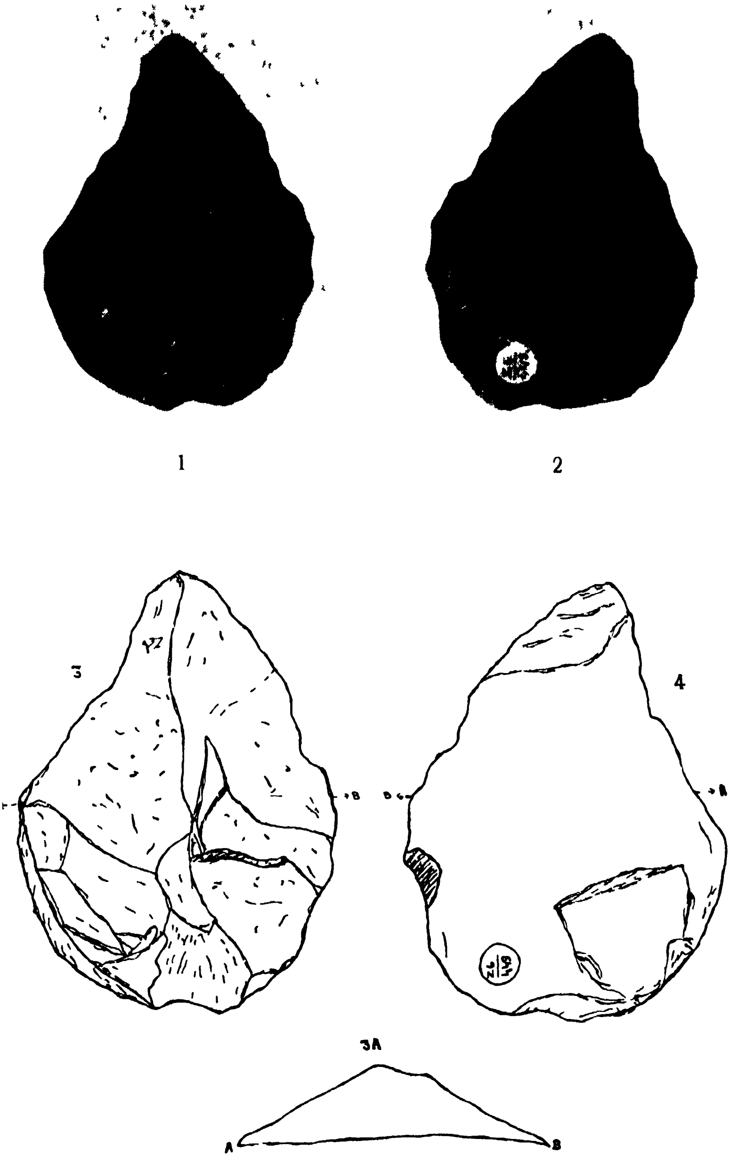
* J. W. Evans, *Ancient Stone Implements of Great Britain*, p. 325.

† Sollas, *Ancient Hunters*, p. 210, Figs. 97 (*b*), B (*a*).

‡ par E. Passemard, *Les Stations Palæolithiques du pays Basque*, p. 123, Fig. 70.

PLATE V.



A Mousterian Coup de Poing from Kibbanhalli, Mysore.

As has already been remarked, all the implements described in this paper are fashioned out of flakes which have been worked on one side only—a characteristic and peculiar feature of the Mousterian industry of the Continent, and since the implements compare very favourably with Mousterian types it has been suggested that they probably mark a culture similar to the Mousterian of Europe, but no implication of a similar age in time is intended.

I will be failing in my duty if, before concluding, I don't express my deep indebtedness to Prof. P. Sampat Iyengar, M.A., for very generously allowing me to study his vast collection of palæolithic implements and giving helpful criticisms and suggestions in their study.

THE PRESENT POSITION OF INTERNATIONAL TRADE.

(*Economic Committee, League of Nations.*)

The work of the League of Nations may be divided into parts, one, the spectacular, in which it seeks to compose the political differences among the various states and the other, the intellectual, in which it seeks to inform and enlighten the people of the world on social and economic matters. The achievements of the League of Nations on the spectacular side, though very substantial, have been on an altogether too small a scale considering the magnitude of the political issues that sunder nation from nation. But on the side of spreading enlightenment the League of Nations has to its credit formidable achievements. Though it does not appeal to the imagination of the politician and the man in the street who expect big results from what is an international organ and a world association of states the information that it disseminates through its various committees—the reports, brochures, studies, monographs, documents, statements—acts as a leaven on the warring people of the world and is certainly an influence that makes for peace, co-operation and co-ordinated action.

Among such publications the document under review must take high rank. Within a short compass the present condition of international trade is described. And the impression is conveyed that all is chaos where but a few years ago there was an orderly and continuous exchange of goods and movement of capital from country to country. No more conclusive proof of it can be found than the sharp and steep decline in the foreign trade of the principal countries in the world. Thus between 1929 and 1931 the set-back in international trade, expressed as a percentage, has been 41.5 per cent on imports and 43.1 per cent on exports.

Such a phenomenon calls for a scientific investigation and nobody is better fitted to carry it out than the League of Nations which not being interested in the commercial policy of any particular state can survey impartially and critically the numerous tariff charges and trade restrictions which have all but strangled international trade. The League makes a distinction between protectionist measures which are the normal feature of the trade policy of various countries and those which arise out of a policy of economic nationalism. These measures are further reinforced by certain restrictions on the free flow of capital and goods necessitated by the present financial and monetary disorder. Thus import duties and export duties are illustrative of the purely protectionist measures while import boards, quotas, clearing arrangements, exchange control, import licences or monopolies are so many defences put up against the onrush of the economic and financial crisis. All these are briefly set forth in the document.

There is also a useful chapter on the correlation between unemployment and the collapse of international trade. Certain industries are selected which figure prominently in the export trade of the principal countries and with respect to each industry the decline in exports is brought into juxtaposition with the increase in unemployment. It has not been possible to establish a mathematical correlation of the two figures for want of evidence as to the falling off in home consumption, extent of effective stocks, etc.

In the annex to the document there is a recapitulation by countries of the various measures adopted for the control and regulation of foreign trade. At a glance one gets an idea of the articles in each country which are subject to one or other of the methods of trade restriction. The information given in this section will be of great value to the importers and exporters.

One word by way of criticism. The document is obviously intended for wide circulation. Its purpose, one may guess, is to inform the traders about the condition of international trade at present and also to instruct the world in general about the error of its ways in placing so many restrictions on the free movement of capital and goods with which the prosperity of so many nations is bound up. But the document, regarded from this angle, slightly defeats its own purpose. It is a mere skeleton and very sparing in expression. Most-favoured-nation clause, quotas, clearing arrangements, import licences, exchange dumping, are to the uninitiated in economic science just so many terms mystifying and not clarifying the issues of the day. Brief explanatory notes would have gone a long way to enable the reader to grasp the inner meaning and true purport of these measures and also follow their repercussion on the course of the world trade. In a document of this description little can be gained by brevity. Economics is a science which speaks in the language of the market place and when difficult ideas or strange terms are imported into it, care must be taken to bring them within the understanding of the reading public.

V.L. D'S.

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QUANTITATIVE ORGANIC SEMI-MICRO METHODS OF COMBUSTION.*

BY B. L. MANJUNATH AND S. SIDDAPPA.
(*Department of Chemistry, Central College, Bangalore.*)

The earliest attempt at the development of a semi-micro method of determining the percentage of carbon and hydrogen in organic compounds was that of Collie (*J. Chem. Soc.*, 1904, **85**, 1111). He devised an apparatus by which the estimations were carried out by a purely gaso-volumetric procedure using 15 to 20 mg. of substances. Similar methods were put forward later by Pouget and Chouchack (*Bull. Soc. chim.*, 1908, **3**, [**4**], 75), Hackspill and Heeckeren (*Compt. rend.*, 1923, **177**, 59) and Hackspill and D'Huart (*Ann. Chim.*, 1926, **5**, [**10**], 96).

Wise (*J. Amer. Chem. Soc.*, 1917, **39**, 2055) was the first to adapt the micro methods of Pregl to centigramme analysis. On account of the relatively larger quantities of substances taken, he carried out the combustions in a stream of oxygen, using platinised asbestos as catalyst and asbestos impregnated with copper oxide as the oxidising material. The products formed were collected in absorption vessels similar to those of Pregl. Lauer and Dobrovolny (*Mikrochemie*, Pregl-festschrift, 1929, p. 243) closely follow Wise in the manner of filling the combustion tube and introduce, further, some of the special features of Pregl's method, such as the pressure regulator, etc. Reference must also be made to the contributions of Polonowski (*Bull. Soc. chim.*, 1924, **35**, [**4**], 414) and Wahl and Sisely (*Compt. rend.*, 1928, **186**, 1555; *Bull.*

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* This paper is taken from the thesis submitted by S. Siddappa for the degree of Master of Science, in the University of Mysore.

Soc. chim., 1928, **43**, [4], 1279). The latter recognized the advantages resulting from the taking of small amounts of material for combustions and described a procedure which was an adaptation of the classical method of Liebig.

Heslinga (*Rec. trav. chim.*, 1924, **43**, 551) introduced specially prepared manganese dioxide as a catalytic oxidising agent in semi-micro analysis. This substance, however, has to be frequently regenerated outside the combustion tube by a wet process. In the method of Berl and Burckhardt (*Ber.*, 1926, **59**, 890) lead chromate is employed as the oxidising material. The water formed is absorbed by conc. sulphuric acid, and carbon dioxide is estimated either gaso-volumetrically or by absorption in a soda-lime tube. Later, for the analysis of nitrogenous organic compounds lead peroxide was introduced into the combustion tube, according to the method of Pregl (Berl, Schmidt and Winnacker, *Ber.*, 1928, **61**, 83). But the principal disadvantage in the method of Berl and collaborators is that the weighed material has to be mixed with dry powdered lead chromate and introduced into the combustion tube as in the case of nitrogen determinations.

Sucharda and Bobranski's publication "Halbmikromethoden zur automatischen Verbrennung organischer Substanzen und ebullioskopischen Molekulargewichtsbestimmung" appeared in 1929. Their methods follow those of Pregl very closely even in the matter of small details, and by means of a very ingenious device they make the process of combustion completely automatic. When we attempted to work this method in our laboratory we found that the automatic regulator would not function* possibly owing to differences in the nature of the gas supply and its pressure. Further experiments have led us to several modifications and improvements which simplify the process considerably. The result has been the evolution of methods which may be claimed to be of general applicability.

In developing the present methods the following points have been kept in view:

(*a*) to simplify the apparatus and procedure so that they may replace the macro methods in regular instruction,† and

---

* *Cf.* Calvet and Mosquera, *Chem. Abs.*, 1933, **27**, 244.

† Berger, *J. pr. Chem.*, 1932, **133**, [II], 1. See also Hans Meyer, "Analyse und Konstitutionsermittlung Organischer Verbindungen," 5th ed., 1931, pp. 99-109 and p. 124; Weygand, "Quantitative analytische Mikromethoden der organischen Chemie," 1931, pp. 130-148 and 54-66.

(*b*) to follow closely the micro methods of Pregl so that the experience gained here may serve as a valuable preliminary to training in organic quantitative micro analysis.

The principal advantages are:

(*a*) very considerable saving in materials,

(*b*) comfort and convenience in working, and

(*c*) shortness of the duration of the analyses.

It is hoped that as a result of the publication of this paper semi-micro methods of combustion will come into more general use.

THE BALANCE.

Although a micro balance is not necessary, an accurate balance by which the fourth place after the decimal can be determined with absolute certainty is essential.* It will, however, be a great advantage to have a balance wherein the fifth place after the decimal can be satisfactorily estimated. The pans should be fitted with side arms for suspending the absorption tubes during weighings. Suitable balances have been put on the market by several manufacturers and of these Kuhlmann's "Schnellwaage, No. 4*a*"† is recommended. Its great advantage is constant sensitivity at varying loads. With this balance 20 mg. can be weighed with the same degree of accuracy as 2 mg. in the micro balance.

The technique of weighings is the same as that recommended by Pregl‡ such as acclimatisation, use of counterpoises, etc.

The following results of an analysis will illustrate the importance of the considerations mentioned above:

Substance.	Water.	Carbon dioxide.	Per cent. of	
			hydrogen.	carbon.
0.02458 g.	0.02037 g.	0.07219 g.	9.21	80.07
0.0246 g.	0.0204 g.	0.0722 g.	9.22	80.04
0.0245 g.	0.0204 g.	0.0722 g.	9.25	80.35
0.0246 g.	0.0203 g.	0.0721 g.	9.18	79.98

---

* *Cf.* Bobranski and Sucharda, *loc. cit.*, p. 28.

† Wilh. H. F. Kuhlmann, Steilshoperstrasse, 101-103, Hamburg 33.

‡ Pregl, "Quantitative Organic Mikroanalysis," 2nd ed., translated by Fyleman, 1930.

THE DETERMINATION OF CARBON AND HYDROGEN.

Outline.—20 to 30 mg. of material are taken for each analysis. The combustion tube is filled according to Pregl (*loc. cit.*, p. 30), and the oxidation is carried out in the presence of pure oxygen with platinised asbestos as catalyst. The products formed are received in suitably filled Blumer's absorption tubes and estimated.

Oxygen and its introduction into the combustion tube (Fig. 1). —Pure oxygen from liquid air,* obtained in steel cylinders, is bubbled through water and filled into the gas-holder. The connecting tubing is artificially aged according to Friedrich (Pregl, *loc. cit.*, p. 21). Similar tubing should also be employed for all connections between the gas-holder and the absorption train.

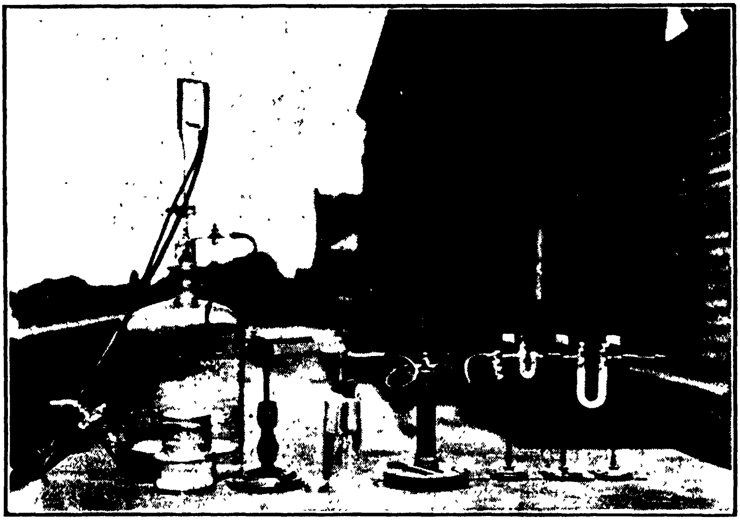

Fig. 1.

The gas-holder is connected to Pregl's pressure regulator (*a*) with a precision pinch-cock (*b*) in between, to regulate the flow of oxygen. The pressure regulator is then connected to a U-tube with bubble counter (*d*) interposed by a stop-cock (*c*).

A few drops of pure 50 per cent. caustic potash are carefully run into the bubble counter, with the help of a thin tube, so that the inner tube just touches the liquid. Small wads of cotton are inserted into the side tubes and the U-tube is nearly filled with ascarite and covered with a little cotton. The glass stopper is warmed, coated with Krönig's cement and screwed into position. The bubble counter is then calibrated as described by Pregl (*loc. cit.*, p. 27), "that is, the gas volume that passes the tube system in one minute must be correlated with the frequency of the bubbles."*

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* Oxygen generated from Oxone is also of the necessary purity.

Next comes another U-tube (*e*) with ground stoppers. This is filled with dehydrite and covered with a little cotton. The stoppers are coated with good quality vacuum stop-cock grease and inserted into position. This U-tube is followed by a tapered thermometer tube (*f*) which leads into the combustion tube through a rubber cork. These absorption tubes (*d* and *e*) should be refilled after using them for 40 to 50 combustions.

The two U-tubes and second U-tube and thermometer tube are connected by means of 20 mm. lengths of thick-walled impregnated rubber tubing (Pregl, *loc. cit.*, p. 51)† and the glass parts should be flush with one another.

The combustion tube and its accessories (Figs. 2 and 2*a*).—The combustion tube is of hard Supremax glass of 12 mm. outer diameter and length, 53 cm.‡ To one end is joined a 2 cm. length of tubing of the same diameter as that of the side tubes of Blumer's absorption tubes.

The tube is filled as follows (Pregl, *loc. cit.*, p. 30):

It is repeatedly rinsed with chromic acid, washed with distilled water and carefully dried. Then a 7 mm. length of choking plug is inserted. This is accomplished by adding cleaned and freshly ignited asbestos in three portions through the wider end of the combustion tube and pressing it home each time with a clean glass rod. The degree of gaseous friction at this point is determined by inserting the tube into the hollow mortar maintained at 190°, and determining the number of c.c. of air that will pass through per minute, at a head of

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* This is accomplished thus: The U-tube is connected to the Mariotte flask (Pregl, *loc. cit.*, p. 49) and air is allowed to pass through. The displaced water is collected and measured. The number of bubbles corresponding to 10 c.c. are counted. From this result we get the number of bubbles corresponding to any given volume, say 4 or 5 c.c. This is checked by adjusting the pressure regulator and the syphon tube of the Mariotte flask, so that only 4 or 5 c.c. pass through per minute, and counting the number of bubbles. We thus derive the bubble frequency, namely, the number of bubbles per 10 or 15 seconds corresponding to a given volume.

† It is advisable to moisten the glass surfaces with a little glycerine and to wipe off all excess before inserting the rubber connections. Further the bore of rubber tubes also should be similarly treated, as recommended by Pregl, to prevent sticking.

‡ Sucharda and Bobranski, *loc. cit.*, p. 10.

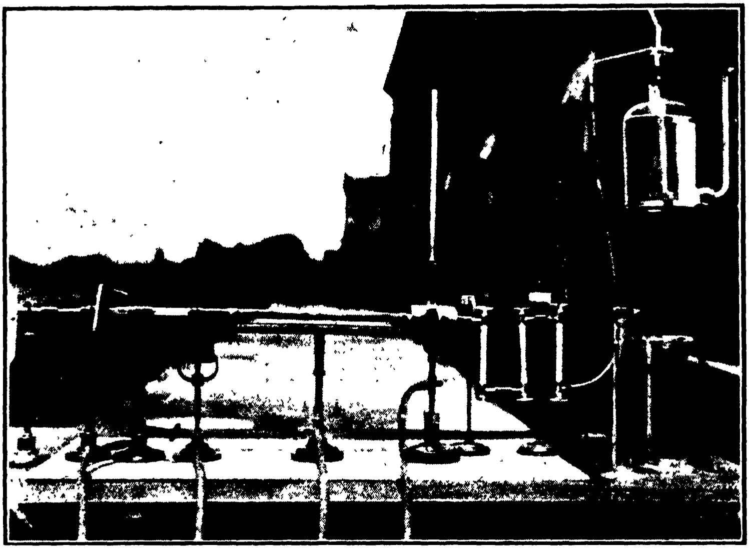

Fig. 2.

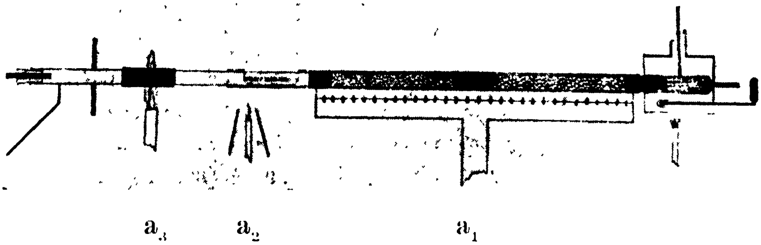

Fig. 2 a.

50 to 60 mm. of water in the pressure regulator. This should be 5 to 6 c.c. Otherwise adjustment is made accordingly either by pressing or loosening the plug.

Lead peroxide asbestos is inserted to a length of 30 mm. This is best accomplished by adding it in small portions and allowing it to slide along the tube. Tapping should be avoided as it will tend to compress the substance. A small wad of asbestos will keep it in position. At this stage it is advisable to test the degree of gaseous friction inside the tube, as before, after inserting it into the heated mortar. Any diminution in bubble frequency will be due to close packing of lead peroxide asbestos. Adjustments are made so that the original bubble frequency corresponding to 5 or 6 c.c. is restored. The empty portion of the tube is cleaned by wiping thoroughly with a small piece of cloth attached to a long wire, in order to free it from particles of lead peroxide dust.

Then follows a layer of loosely packed silver wool or gauze* 30 mm. in length and again an asbestos wad.

The oxidising filling, consisting of a mixture of equal parts of wire form copper oxide and lead chromate (grains of 2 mm. diameter) is added to a length of 10 cm. and covered with an asbestos wad. The empty portion of the tube is wiped clean and a 30 mm. layer of 20 per cent. platinised asbestos is introduced. Care should be taken to allow the substance to slide along the wall of the tube as in the case of the introduction of lead peroxide asbestos. This is followed by another asbestos wad. It is advisable to test once again the degree of gaseous friction in the tube. For this purpose the tube is covered with the long brass cylinder (a_1) so that one end of it covers half the length of silver gauze, and is inserted into the heated mortar. The tube burner is lighted (*cf.* Sucharda and Bobranski, *loc. cit*, p. 11), and after some time the bubble frequency is determined. If necessary, adjustments are made so that at least 4 to 5 c.c. of air pass through per minute.

The tube is again wiped and the filling completed by adding the oxidising mixture to a further length of 10 cm., then an asbestos wad and finally a roll of silver gauze 15 mm. in length. The empty portion of the tube is once again wiped clean.

The combustion tube is provided with an asbestos-lined thin-walled brass cylinder 26 cm. in length (a_1). This cylinder encloses the tube from the first silver gauze to about half of the second one, and is supported on a long burner.† The portion of the tube filled with lead peroxide asbestos is covered with asbestos paper and inserted into a mortar‡ whose temperature can be maintained constant at about 190° by adjusting a micro-burner underneath.

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* The silver used for tube filling must be cleaned by reducing it in a current of hydrogen and subsequently igniting it in a current of oxygen (Pregl, *loc. cit.*, p. 27).

† Sucharda and Bobranski, *loc. cit.*, p. 12. For an electrical combustion furnace, see Berger, *loc. cit.*

‡ A hollow mortar (Pregl, *loc. cit.*, p. 36) with boiling decaline is an advantage. However, when the mortar is used merely as an air bath, the temperature can be maintained surprisingly constant for long periods, by adjusting the micro-burner underneath.

The tube is also provided with two smaller asbestos-lined brass cylinders. The first of them is 60 mm. in length (a_2), and is placed next to the long cylinder. It is opened out at the top as indicated in the diagram and the combustion boat will be clearly visible from above. A micro-burner is placed underneath its wider end, for decomposing the material. The second small cylinder (a_3, 40 mm. in length) is placed at a distance of 35 to 40 mm. from (a_2), above a close-fitting freshly oxidised spiral of copper gauze introduced into the tube, and is heated by a Bunsen burner. An asbestos disc is put on the tube at a distance of 10 mm. from (a_3) to prevent the radiation of heat from affecting the rubber stopper. A further support to the tube is given near the mouth to prevent its bending as a result of continued heating during several combustions.

The absorption tubes.—Blumer's tubes (Sucharda and Bobranski, *loc. cit.*, p. 15) are employed.* For the absorption of water one of them is filled with dehydrite. The tube is first cleaned and dried. One of the stoppers is covered thinly with a small amount of good quality vacuum stop-cock grease and screwed into position. A small wad of cotton is inserted through the open end and pressed into position above the stopper with the help of a glass rod, so that it forms a thick layer of about 5 mm. The rest of the tube is filled with granular dehydrite, covered with a wad of cotton and the second stopper suitably greased is screwed home. It is advisable to make a mark on one of the stoppers so that only that end is always connected to the combustion tube.

The second Blumer's tube is filled in a similar manner so that ⅔ its length is occupied by ascarite and ⅓ by dehydrite, with a 2 mm. layer of cotton separating the two.

The tubes are joined to one another by a rubber connection and all the air is displaced by passing through them slowly about 150 c.c. of oxygen. The stoppers are then turned through 180°.

Before weighing, the side tubes of each of them are cleaned by means of a small wad of cotton attached to a steel wire. They are successively wiped with moist flannel and 2 pairs of clean chamois leather pieces,† and allowed to stand on a frame

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* The Pregl tubes are unsuitable because of the formation of relatively larger amounts of water which tends to choke the capillary constructions thereby causing back pressure.

† Sucharda and Bobranski, *loc. cit.*, p. 16.

(Pregl, *loc. cit.*, p. 44) for ten minutes. They are then suspended in the balance and their weights determined. An aluminium fork is employed to handle them after wiping.

The dehydrite tube usually lasts for 30 to 40 combustions and the ascarite tube for about 4 to 6. It is advisable to work with two pairs when carrying out a number of successive combustions and to keep a good stock of spare tubes.*

Preliminary roasting and blank tests.—Preliminary roasting is carried out thus: The long burner and the micro-burner under the heating mortar are lighted. The temperature in the mortar is adjusted to 190°. The narrow end of the combustion tube is connected to the Mariotte flask and the syphon tube is so adjusted that 5 c.c. of air per minute are drawn through the combustion tube. The brass cylinder (a_3) is moved over to the end of the combustion tube and heated strongly by a Bunsen burner. The flame, with the brass cylinder above, is gradually moved towards the tube filling. The empty portion of the tube is thus thoroughly ignited and the burner removed. When the open end of the combustion tube is sufficiently cool, the rubber stopper is inserted,† and the Mariotte flask is disconnected. The absorption train is then joined on by means of the thermometer capillary and oxygen is allowed to pass through at the rate of 5 c.c. per minute by adjusting the pressure regulator.‡ The roasting is continued for at least 3 hours. The apparatus is then ready for carrying out a blank test.

With the long burner lighted and the mortar maintained at 190°, the absorption tubes are weighed as described already. The ascarite tube is connected with the dehydrite tube in such a manner that the gases coming from the latter pass through ascarite first. A piece of impregnated rubber tubing 20 mm. in length is used to join the two. With another piece of the same length, the other end of the ascarite tube is connected to a Blumer's tube filled with dehydrite. This acts as a safety tube. The weighed dehydrite tube is then attached to the combustion tube by another piece of impregnated tube (15 mm. length).

---

* The entire apparatus can be obtained from the firm, Greiner and Friedrichs, G.m.b.H., Stützerbach in Thür. Mention may also be made of Paul Haack, Garelligasse 4, Vienna IX/3, for some specialities like the hollow mortar, precision pinch-cock, Krönig's cement, rubber tubing, etc.

Oxone, ascarite and dehydrite are obtained from the Central Scientific Co., 460, East Ohio Street, Chicago, and the other chemicals "nach Pregl" from E. Merck, Darmstadt.

† The bore and the outer surface of the rubber stopper should be moistened with just a trace of glycerine and wiped clean. This should be done from time to time in order to prevent its sticking to the glass surface.

‡ After adjusting the pressure regulator now, the pressure under which oxygen enters the tube should not be altered. Occasionally, however, it may become necessary to determine the bubble frequency when the narrow end of the tube is open and to make minor adjustments.

The bores of the connecting pieces of impregnated tubes should be moistened with glycerine each time before use, by passing through them a small wad of cotton containing a little glycerine. Any excess is wiped out by means of a dry cotton wad. The glass parts in all the above connections should be flush with one another.

The safety tube is connected to the Mariotte flask and the stoppers of all the Blumer's tubes are so turned that oxygen passes through the combustion tube. The bubble frequency, corresponding to 5 c.c. per minute, is adjusted by raising or lowering the syphon tube of the Mariotte flask.

A few small asbestos paper discs are put between the mortar and the first rubber connection to prevent its rapid deterioration on account of radiated heat. The copper heater from the mortar is placed on the open portion of the side arm of the dehydrite tube.

The roasting is continued for one hour. Occasional attention is paid to maintain the constancy of temperature in the mortar. At the end of the period, the Mariotte flask is disconnected. The absorption tubes are closed and detached. The safety tube is connected to the neck of the combustion tube by means of impregnated tubing.

The absorption tubes are cleaned, wiped and after remaining for ten minutes on the stand, are weighed. If the apparatus is in a satisfactory condition, they should show no increase in weight in the fourth place after the decimal; otherwise the entire apparatus is examined carefully for leaks, etc., and the roasting continued till constancy of weight in blank tests is ensured.

When the apparatus is to be set aside for the day, the burners are all put out. The tube is allowed to cool and oxygen from the gas-holder is stopped. The stop-cock (*c*) and the stoppers of the U-tube (*e*) are turned through 90° and finally that at the end of the safety tube through 180°.

A tube thus prepared lasts for at least 75 to 100 combustions. If a number of halogenated organic compounds are being analysed, it is necessary to clean the smaller silver gauze, occasionally, as described already.

The course of analysis.—Before the analysis of unknown substances is undertaken, it is advisable to carry out the combustion of one or two known substances, such as acetanilide, allantoin, etc.

In carrying out a combustion, it is best to follow closely the following procedure:

1. The stoppers of the stop-cock (*c*), the U-tube (*e*) and of the terminal safety tube are turned to allow the passage of oxygen through the combustion tube. Oxygen is let in from the gas holder and its flow into the pressure regulator is controlled by the precision pinch-cock. The long burner and the micro-burner under the mortar are lighted and the temperature of the mortar is regulated to 190°.

2. The absorption tubes are cleaned, wiped and placed on the stand.

3. Oxygen is stopped from the gas holder and the empty portion of the tube is rapidly ignited in the manner already described. The absorption train is connected again and oxygen is let in. The bubble frequency is tested. The impregnated rubber connections are treated with glycerine and wiped. The spiral of copper gauze is ignited and allowed to cool in a desiccator.

4. The substance (20 to 30 mg.) is weighed into a suitable platinum or porcelain boat* and placed in a desiccator. The absorption tubes are then weighed, inter-connected and, together with the material, are moved near to the combustion train.

5. The terminal safety tube is disconnected and the tip of the combustion tube is carefully wiped. The dehydrite tube is attached to the combustion tube and the ascarite tube to the safety tube, which in turn is connected to the Mariotte flask with its syphon tube raised. Asbestos discs are placed between the mortar and the first rubber connection, and the copper heater on the open portion of the side arm of the dehydrite tube. The stop-cock of the gas holder is closed.

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* Before use the boats should be boiled with nitric acid, washed, dried, ignited and allowed to cool on copper block inside a desiccator.

For the manipulation of liquids with low boiling points, see Pregl, *loc. cit.*, p. 70 and Sucharda and Bobranski, *loc. cit.*, p. 27. In the case of high boiling liquids (b. p. above 200°) one drop is put into the boat and weighed out in the usual manner.

6. The rubber cork is removed from the mouth of the combustion tube, the boat is inserted by means of a pair of forceps and pushed in with the help of a clean dry glass rod, so that it becomes visible from the open portion of the brass cylinder (a_2) and is not more than 1 cm. from the tube filling. The oxidised copper spiral is introduced into position; the rubber stopper is then inserted and the combustion tube is connected with the absorption train. The stoppers of the Blumer's tube are all suitably turned to allow the passage of gas.

The apparatus is tested for any leaks by closing the stop-cock (c) and lowering the syphon tube of the Mariotte flask. After a few seconds no more bubbles should rise in the flask.

7. Oxygen is let in and bubble frequency is adjusted by raising or lowering the syphon tube of the Mariotte flask.

8. The burner under the brass cylinder (a_3) is lighted. When it is red hot, a micro-burner with a small flame, the size of which depends upon the nature of the substance that is being oxidised, is placed under the wider end of the brass cylinder (a_2).

After a little time the substance begins to decompose. This should be slow and gradual and it is best to work with a very low flame. At this stage it is usual to notice a temporary diminution in bubble frequency. The entry of oxygen, however, should not stop and any back pressure, as will be indicated in the bubble counter, should be carefully avoided.

The copper heater is used to drive any moisture condensing in the side arm of the dehydrite tube into its stopper. Occasional attention is also paid to maintain constancy of temperature at 190° in the mortar.

The decomposition will be over in a short time (2 to 5 minutes). The micro-burner is replaced by a good Bunsen burner and the charred particles are completely burnt out.

At this stage, the passage of bubbles in the Mariotte flask will become very slow although the bubble counter may indicate a slightly increased rate of entry of oxygen into the combustion tube. Water will collect in the stopper of the dehydrite tube and the absorption of carbon dioxide in the ascarite tube will be apparent.

9. The regular combustion is now over. 100 to 150 c.c. of oxygen are allowed to pass through, in order to wash out all the products of combustion into the absorption tubes. This

volume is determined by measuring the water issuing from the syphon tube in a graduated cylinder.

During this period the Bunsen burner, together with the brass cylinder (a_3), is gradually moved till the latter joins the cylinder (a_2). In this manner the empty portion of the tube is thoroughly ignited.

If successive combustions are to be carried out, material is weighed out into a second boat and another set of Blumer's tubes are got ready.

10. As soon as the required volume of water is collected in the measuring cylinder, the syphon tube is raised, and the absorption tubes are disconnected after closing the stoppers.

If a second combustion is to be carried out, another set of weighed absorption tubes are attached to the combustion tube, and the procedure repeated. On opening the rubber cork, the copper spiral and the boat are removed by means of a platinum hook. The second boat followed by the copper spiral is introduced, and the cork is re-inserted. Otherwise, the tube is allowed to stand by in the manner already described.

The absorption tubes are cleaned, wiped and weighed in the usual manner and the results are then calculated.

A variety of substances with varying chemical compositions have been analysed and the accuracy of the determinations is ±0.2 per cent.

Some results :

Substance and its formula.	Wt. taken.	H_2O	CO_2	Per cent. of			
				Hydrogen		Carbon	
				Found	Theoretical	Found	Theoretical
	g.	g.	g.				
p-Phenyl phenacyl ester of lignoceric acid, $C_{38}H_{58}O_3$.	0.02408	0.02250	0.07164	10.4	10.4	81.1	81.1
Allantoin, $C_4H_6N_4O_3$.	0.01361	0.00477	0.01507	3.9	3.8	30.2	30.4
2 : 4 Dihydroxy isophthalic acid, $C_8H_6O_6$.	0.02982	0.00853	0.05304	3.2	3.1	48.5	48.5
Diethyl ester of 2 : 4 dihydroxy isophthalic acid, $C_{12}H_{14}O_6$.	0.02766	0.01354	0.05742	5.4	5.5	56.6	56.7
p-Bromphenacyl ester of $C_{23}H_{46}O_2$, $C_{31}H_{51}O_3Br$.	0.01664	0.01375	0.04120	9.2	9.3	67.5	67.5

THE DETERMINATION OF NITROGEN.

Although the volumetric determination of nitrogen in organic compounds, according to the micro method of Pregl, yields accurate results without considerable difficulty, still, where a micro balance is not available, the semi-micro method affords a valuable alternative. Suitable methods and apparatus have been advanced by Berl and Burckhardt (*Ber.*, 1926, **59**, 897), Lauer and Sunde (*Mikrochemie*, Preglfestschrift, 1929, p. 239) and Sucharda and Bobranski (*loc. cit.*, p. 30). The following procedure which is a close application of Pregl's micro method to centigramme analysis has been found to be equally accurate.

The carbon dioxide generator.—Medium sized pieces of marble are kept in water and boiled for a few hours under diminished pressure. They are then washed with a little dilute hydrochloric acid and charged into the middle bulb of a fairly large-sized Kipp's apparatus. The delivery tube (*a*) is provided with a stop-cock (c_1) and is so arranged that the gas is drawn from the top portion of the chamber. A mixture of equal parts of concentrated hydrochloric acid and boiled water is added through the upper bulb. The stop-cock on the delivery tube is opened for a short time so that there is vigorous evolution of carbon dioxide. This is repeated several times in order to drive out all the air in the apparatus. Also, one or two larger pieces of marble are inserted into the central tube to complete the de-æration. A Kipp charged in this manner is allowed to stand for some days during which the process of de-æration is repeated a few times.* It will then deliver carbon dioxide of the specifications of Pregl as judged by the formation of micro-bubbles when slowly let into the azotometer.

The combustion tube, its accessories and the azotometer (Fig. 3).—The delivery tube of Kipp's apparatus is connected by means of pressure tubing to a *Z*-form capillary tube which leads into the combustion tube through a rubber cork.

The combustion tube is similar to the one employed for the determination of carbon and hydrogen but of a total length of 45 cm. For filling it, it is first cleaned and dried. A small asbestos wad inserted through the wider end is pushed to the neck. A layer of freshly ignited wire form copper oxide 90 mm. in length is introduced and covered with a small amount of asbestos. This is followed by a 50 mm. length of freshly reduced copper wire* and covered with a little asbestos. The materials added till now form the permanent filling of the tube.

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* The de-æration process is repeated once a week since hydrochloric acid in the upper bulb comes into contact with air after some time, in spite of the safety tube.

The combustion tube is provided with two asbestos-lined brass cylinders, one 19 cm., and the other 35 mm. in length. The former (b_1) is placed in such a manner that one end of it is about 8 mm. from the neck of the tube. The smaller one (b_2) is used to cover the tube when the substance is being heated by a Bunsen burner. The combustion tube is supported on a stand and is heated along the length covered by the longer cylinder by means of a tube burner.

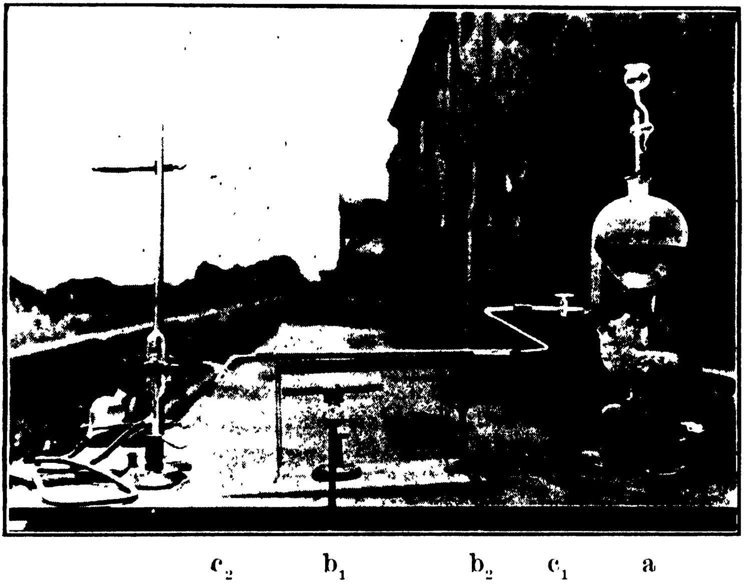

Fig. 3.

The narrow end of the combustion tube is connected to Pregl's stop-cock with long handle† (c_2) which in turn is joined to an azotometer similar to the one employed by Berl and Burckhardt (*loc. cit.*), but with only an ordinary stop-cock above the graduated end. The Pregl's stop-cock is introduced to regulate the rate of entry of gas bubbles into the azotometer. The azotometer is filled with mercury up to a level just above the lower side tube and 50 per cent. potassium hydroxide, prepared according to Pregl (*loc. cit.*, p. 99), is introduced into the levelling bulb.

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* See Pregl, *loc. cit.*, p. 93. This should be replaced after 15 to 20 combustions.

† This stop-cock should be occasionally cleaned in order to remove condensed water.

When a tube is filled for the first time, it is roasted for 10 to 15 minutes in a current of carbon dioxide. Stop-cock (c_2) is then closed and that on the delivery tube opened so that the tube is filled with carbon dioxide under pressure.

The course of analysis.—20 to 30 mg. depending upon the nitrogen content of the substance, are weighed into a mixing tube† and thoroughly mixed with about 3 c.c. of fine copper oxide.

Above the permanent filling of the tube is introduced another 10 cm. layer of wire form copper oxide and covered with a small quantity of fine copper oxide. The substance mixed with fine copper oxide is added into the tube through a small funnel. The mixing tube is rinsed twice with fine copper oxide and the washings are poured into the combustion tube. Then wire form copper oxide to a length of 8 cm. is added.‡

The combustion tube enclosed in the brass cylinders is placed on the stand and connected with the Kipp generator and the azotometer. With the levelling bulb of the azotometer kept low and the stop-cocks fully open, a vigorous stream of carbon dioxide is passed through the tube for 1 to 5 minutes. The long burner is then lighted, the stop-cock (c_2) is closed and the azotometer filled with caustic potash by raising the levelling tube. By means of the long handle of the stop-cock (c_2) carbon dioxide is allowed to enter into the azotometer at the rate of a bubble per second. The bubbles should be completely absorbed leaving only the micro-bubbles to rise in the stem. Otherwise the process of washing out is continued as before and the apparatus is tested to make certain that all the air has been removed.

With the azotometer set, the stop-cock (c_1) is closed and (c_2) is fully opened. The combustion is commenced at the farther end of the tube filling, with a Bunsen burner keeping the brass cylinder (b_2) above. The flame is moved gradually towards the long burner so that the substance is very slowly oxidised as indicated by the entry of gas into the azotometer, which should at no time contain more than two bubbles at the same time. The combustion is completed when the Bunsen burner is brought close to the long burner.

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* The complete apparatus can be obtained from the firm Greiner and Friedrichs.

† An ordinary test tube 50 mm. long and 12 mm. in diameter is used. A tight-fitting cork without any grains is used to close the mouth when shaking.

‡ The filling after the reduced copper is removed each time a combustion is to be carried out and sieved. The two varieties of copper oxide are ignited separately and used for subsequent tube fillings.

Then commences the washing out process. The stop-cock (c_2) is closed and (c_1) is fully opened. The former is very gently adjusted so that gas begins to enter the azotometer at the rate of a bubble per second. The washing is continued till micro-bubbles once again begin to ascend in the tube. During this period the portion of the tube outside the long burner is ignited strongly and the burners are put out.

A few minutes after the micro-bubbles begin to ascend in the tube, the stop-cock (c_2) and the stop-cock on the azotometer side tube are completely closed, and the azotometer is disconnected and moved to a cooler place. The levelling bulb is kept raised and a thermometer is kept near the gas in the stem. After 15 minutes, the volume is read accurately with the help of a lens, after equalizing the pressures by means of the levelling bulb. The temperature and the barometric pressure are noted.

From the volume thus read 1.2 per cent.* is deducted to make allowance for the volume of the alkali adhering to the sides and the results calculated in the usual manner. The accuracy of estimations according to this method is + 0.2 per cent. and a determination usually takes 1½ to 2 hours.

Some results :

Substance and its formula.	Wt. taken.	Volume of Nitrogen.	t°.	Pressure in mm. of mercury.	Per cent. of Nitrogen		
					Calculated from uncorrected volume	Calculated from corrected volume.	Theoretical.
Acetanilide, .. C_8H_9NO.	0.0214 g.	2.23 c.c.	25°	683	10.7	10.6	10.4
Naphthylamine, .. $C_{10}H_9N$.	0.0233 g.	2.25 c.c.	26°	683	9.9	9.8	9.8
Salicylamide, .. $C_7H_7O_2N$.	0.0217 g.	2.20 c.c.	24°	684	10.5	10.4	10.2
m-Nitro phenol, .. $C_6H_5O_3N$.	0.0237 g.	2.40 c.c.	25°	684	10.4	10.3	10.1
Allantoin, .. $C_4H_6N_4O_3$.	0.0117 g.	3.86 c.c.	25°	683	35.9	35.5	35.5

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* *Cf.* Sucharda and Bobranski, *loc. cit.*, p. 34. Weygand (*loc. cit.*, p. 60) considers that the above correction is arbitrary, although its use with several known substances has given accurate results. However, the azotometer may lso be calibrated according to the method of Berl and Burckhardt (*loc. cit.*).

ON THE OCCURRENCE OF GLYCOGEN AND FAT IN LIQUOR FOLLICULI AND UTERINE SECRETION IN *LORIS LYDEKKERIANUS* (CABR).

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INTRODUCTION.

Since in 1858 Bernard (1) demonstrated the occurrence of Glycogen in the placenta of ruminants and in the subsequent year discovered its presence in the rabbit (2), there have been several papers dealing with the subject which have inspired two main lines of investigation. Marshall (4) has given a complete summary of the previous work on the quantitative analysis and metabolism of glycogen in the fœtal tissues and Bowen (5) in his recent contributions on the part played by the Golgi Apparatus and Mitochondria has cited literature bearing on this aspect of the question. Lochead and Cranmer (6) have drawn attention to the fact that the amount and distribution of Glycogen in the placenta in mammals vary in the different orders and in most species the subject has not been completely investigated. The results obtained by Godet, Chipman, Maximow and other investigators have established the fact that the carbohydrate metabolism of the fœtus in the earlier stages of pregnancy is carried out by the maternal placenta, the decidual cells containing the maximum amount of glycogen,—till the role is assumed by the fœtal liver and the embryonic tissues. The variations of the carbohydrate content in fœtal fluids have been quantitatively determined by Paton (7) and his collaborators and its distribution seems to point to the fact that there is a greater concentration in the allantoic than in the amniotic fluid. Langhans (8) and Jenkinson (3) have succeeded in finding glycogen in the uterine epithelium, both superficial and glandular, and in the sub-epithelial connective tissue of the uterus in man, ruminants and rodents. The occurrence of fat in the Uterine fluids in the advanced stages of pregnancy is generally attributed to the fatty degeneration of the decidual cells, but few authors have followed the formation of glycogen in the ovarian ovum and liquor folliculi.

Brambell (9) in his paper on the part played by the Golgi Apparatus in Secretion, also gives a summary of previous work on the subject and the results obtained by these authors appear to prove conclusively that the Golgi bodies influence directly the secreting particles, themselves undergoing changes the while, and are finally extruded in some cases from the glandular cells. The mitochondria are not believed to take any direct share in the functional activity of the cells. In working on the pancreatic cells of the mouse Nassonov (10) has experimentally established the relation of the changes in the Golgi bodies with the sequence in the stages of secretion and regards the former therefore as the seat of its origin.

The results of my studies establish that the Golgi bodies in the Follicle and Uterine gland cells of Loris become active, grow and divide during the secretory activity and the mitochondria are not passive during the whole process. It seems to me that there is just as much evidence to involve the mitochondria as there is in favour of the Golgi apparatus, in the elaboration of the secretion granules. This paper records the occurrence and distribution of glycogen in the ovarian ovum and of fat and glycogen in the liquor folliculi on the one hand and on the other the secretions of the Uterine glands. It is proposed in the end to examine the evidence in support of the view that besides the Golgi bodies, mitochondria also assist in the formation of the secretions.

MATERIAL AND METHOD.

I have obtained the uterus and the ovaries of the non-pregnant and pregnant forms in various stages, out of animals kept in captivity. For Golgi and Mitochondria, Mann-Kopsch Osmic acid and DaFano and Cajal's silver nitrate techniques have been employed. Golgi's Arsenious acid and silver nitrate method also has been used and in the three cases of silver impregnation, the time of fixation has been reduced to one-half of that recommended in view of the. high room temperature in South India. For glycogen and fat, Zieglwallner's Chrome-Osmic and Sublimo-Osmic methods have been employed, followed by Best's Carmine.

For secretory granules, Schridde's modification of formol-chrome technique and Regaud's Formol-bichromate method have been used, followed by Saffranin, or methyl blue and Borax Carmine or acid fuchsin.

As the bits of the same tissue were used for the purpose of fixation in the above fluids, it is possible to follow in the slides the sequence of changes in the cell inclusions and their interrelation.

THE STRUCTURE OF THE UTERUS.

In South India the slender Loris breeds twice in the year ; the sexual season falls in April-May and October-November. This is usually heralded by a wide awake alertness on the part of both sexes in seeking for a mate. The period of proœstrum is marked by a slight sanguineous discharge which has been reported to occur in Tarsius by Startz and Herwerden (11) and as in *Macacus* and *Semnopithecus* in which Heape (12) has studied the subject in great detail, the cycle is divisible into four periods to which I shall refer in the following paragraphs. The other indications of the arrival of the breeding season are a swelling of the external genetalia in both sexes and the descent of the testes in the males to the region of the groin, where they form external swellings, but without any distinct scrotum. The proœstrum lasts for six to seven days and the œstrum for a similar period during which it is not unusual to meet cases in which two or even three males are found clinging to a single female who submits to this strange procedure. However, only one male succeeds finally in effecting coition. I have noticed that when bunches of males are thus attached and failure to copulate results, the female passes into a short metaœstrum of a fortnight during which the activity of the generative organs subsides, followed by another brief œstrum, known as the diœstrous cycle. The number of diœstrous cycle is limited to two and if copulation does not occur. the female passes into a prolonged period of anœstrum, but a polyœstrous cycle in the Loris has not come under my notice.

The menstrual cycle in the Loris may be divided into (1) the period of rest; (2) the period of growth; (3) the period of degeneration; and (4) the period of recuperation.

The Period of Rest.—The Uterus of the non-pregnant Loris before the menstrual cycle, measures from the cervix segment to the base of the fundus 8 mm. and across the cornu 14-15 mm. and the thickness 4 mm. In transverse sections, the uterine chamber is represented by a narrow slit disposed in a zigzag fashion, the muscular layers including those of the septum dividing the body of the uterus are extraordinarily developed and the glands are closely packed together in the submucosa. The epithelial investment composed of short cubical cells form a close and continuous lining for the cavity and passes into the ducts of the glands. The glands are more densely aggregated in the region of the cornu than in the body of the uterus. The interglandular stroma is composed of muscular fibres and connective tissue corpuscles which are generally spindle-shaped. There is no activity of cell-division either in the epithelial layer or subepithelial mucosa or the stroma. The vessels are comparatively narrow and an unequal distribution of them in the deeper and superficial regions of the uterus is noticeable, a larger number of capillaries occurring in the surface area.

The Period of Growth.—This involves the increase in the number of nuclei in the outer portions of the stroma, which leads to a considerable swelling of the head end of the uterus. There is little or no change in the deeper parts of the stroma, where, however, the blood vessels become larger. The swelling of the stroma which later extends to the more posterior divisions of the uterus, produces a tension on the lining mucosa which together with the glands is stretched. It is to be mentioned, however, that the congestion of the epithelium is localised, being confined to the anterior divisions while hyperplasia of the vessels takes place all over the stroma and immediately below the mucosa almost throughout the uterus.

The Period of Degeneration.—The onset of menstrual period is heralded by the appearance of slight streaks of sanguineous discharge through the swollen genital orifice and the preceding stages are marked by the culmination of the hypertrophy of the mucosa, the lining epithelium and the blood vessels and the glands. The congested capillaries break out, extravasating the stroma, where the leucocytes now abound. The uterine glands now possess dilated lumina and are in secretive activity. The nuclei of the stroma are long and chromosomes are reticular and are deeply stainable. In the deeper parts, they enter at this stage, upon the mitotic phase of division and the stroma itself is loose in the more superficial areas where the lacunæ are beginning to be formed. I have followed this part of the subject in detail and have noticed that the formation of lacunæ in the subepithelial tissues is due to two causes. In the first place, the cells of the mucous layer become large and develop vacuoles which running together invest the cells with the appearance of large goblets of secretive formations. The secretions of the cells accumulate below the epithelium and in sections the mucoid substance presents a fibrillar appearance whose continuous pressure lifts large patches of the epithelial lining. The space thus produced between the deeper mucosa and epithelial membranes is also filled with the secretions of the uterine glands, and the continued disintegration of the sub-mucous tissue is responsible for the production of a second set of lacunæ in the superficial portions of the stroma where the corpuscles of the extravasated blood accumulate. It is the congested capillaries in the superficial regions which break down, while those in the deeper areas remain intact, and consequently few corpuscles of either variety are met with. At this stage, the uterine wall is clearly marked off into two divisions, the upper portions where the stroma is loose and the extravasation of blood in the superficial areas has occurred and then the lower portion where the stroma is dense as in the uterus before the commencement of the menstrual changes, and the glands, blood vessels and the epithelial layer remain unaffected. The exudation of the blood and the secretion of the glands into the uterine cavity take place, by the peeling off of large patches of the epithelial membrane together with the mucous membrane which occur in shreds in the different parts of the uterine chamber. I have noticed that when the lacunæ rupture through, not only the mucous membrane is carried before the blood stream but such portions of the glands as come under its influence. The cells of the epithelial membrane lose their outline and the nuclei become broken up into thick irregular threads of deeply staining chromosomes. The nuclear membrane can hardly be made out. The cells of the mucous membrane, both superficial and deeper layers,—have disintegrated owing to the development of vacuoles, while the nuclei retain their membrane and the chromosomes are granular. The lacunæ of the stroma are long fissures in which gelatinous fluids accumulate in addition to the extravasated blood from the neighbouring capillaries. There are really two kinds of lacunæ formed on a different basis in the different parts of the menstruating uterus of Loris. Those formed in the stroma arise as splits owing to the accumulation of fluids in the connective tissue spaces, the loose character of the tissue being due to the process of the formation of the fluids. Lacunæ also arise in the sub-mucosa where the cells develop large vacuoles whose exudation and disintegrations produce large spaces between the epithelia, mucosa and the stroma. All these lacunæ are filled with the extravasated blood which escapes into the uterine cavity along with the glandular secretions and the connective tissue fluids and watery accumulations of the vacuoles of the mucous cells. The volume of the fluid contents of the uterus is not, however, large and consequently their escape through the external genital orifice is very slight and occurs in smears. In the extravasated blood occurring in the stroma, lacunæ contain a large number of white corpuscles of chiefly the mono-nuclear variety and I have also noticed the polymorphs. During the period of discharge, the inner surface of the uterine chamber at the head end, presents a ragged surface due to devastation of the lining membranes and glands whose remains in the uterine chamber till finally expelled, are noticeable. The menstrual discharge examined under the microscope discloses an opaque fluid base derived from the uterine glands and the blood with granules from the gland and mucous cells, masses of stroma, mucous and epithelial tissue and red and white corpuscles.

The Period of Recuperation.—Heape in his paper on *Semnopithecus entallus* already cited includes in this peroid of re-formation of the mucosa and epithelium the regeneration of the blood vessels and the changes in the stroma including the behaviour of the free leucocytes. The results I have obtained are in accord with his conclusions. The epithelium and the submucous layer are re-formed from the glandular cells and the underlying stroma. In the basal regions of the uterine chamber where there is extensive and complete dehiscence, there is hardly any remains of epithelium to take part in the re-formation of this lining membrane. The glandular cells belonging to structures more deeply situated divide amitotically in the diœstrous phase and this process of reformation of the epithelium is only a repetition of what occurs in the establishment of this layer in the embryonic stages of the uterine development. There is a great streaming movement of the dividing cells towards the uterine chamber from the deeper stroma and the glands and such movements are noticeable even before the shedding of the mucosa and epithelium. The process of reconstruction therefore proceeds or is inaugurated before the disintegration commences. The shape of the newly formed cells which are subject to pressure at the source of origin, is oval and elongated and on reaching the cavity, becomes perfectly cubical.

The extravasation of the blood in the broken down capillaries stops after the elimination from the uterine chamber of the menstrual clot. The contraction of the uterine wall produces at this stage more extensive sanguineous discharge owing to further breaking down of the blood vessels. The flow of the blood is arrested mainly by two causes. The lacunæ in which the blood lies is repaired by the tissue of the stroma becoming compacted whose pressure alone is sufficient for the purpose and the walls of the capillaries and arterioles being regenerated rapidly by the cells of the stroma. I am unable to confirm the description of Heape concerning the re-formation of the blood vessels in *Semnopithecus* and *Macacus*. According to him the protoplasm of the cells bounding the blood-containing spaces flattens out, the nuclei also flattening and elongating; thus fine capillaries are formed. These capillaries become continuous with the deeper parts of the mucosa with the larger pre-existing capillaries. Such capillaries which exist in large numbers during the recuperation period, disappear when the mucosa has shrunk into the resting condition. In Loris, I have not been able to trace the formation of the capillaries along these lines. The picture presented by the uterus in the anterior basal regions at the time of menstrual climax is (1) The uterine cavity is occupied by the hypertrophied epithelial and mucosa shreds together with small quantities of the extravasated blood and the glandular secretions; (2) Leucocytes in the loose matrix of the stroma; (3) The lacunæ of the stroma filled with blood; (4) The capillaries in the stroma and in the neighbourhood of the glands without walls and greatly distended; (5) The mitotic activity of the stroma and gland cells and general migration of the freshly formed cells towards the superficial regions, the lacunæ and the blood vessels; (6) The leucocytes (both baso- and Eosino-phil ones) injesting the red corpuscles which when they escape the leucocytes disintegrate and form pigments. These pigments are finally eliminated by the stroma cells which absorb them. Now in the slides which show these features, it is very easy to follow the process of the reconstruction of the blood vessels. It is true that the stroma cells lying in the immediate vicinity of the blood vessels, become flattened out and elongated and by applying themselves on the sides of the spaces give rise to the walls of the capillaries. But this is not how new vessels arise. During the process of the repair of the walls fresh offshoots in the form of minute canaliculi are produced from the capillaries which join those stroma lacunæ which have not closed up. The old capillaries persist where their walls are re-established, but in several places, the rapid proliferation of cells in the stroma leads to their abolition. Their place, however, is taken by the new vessels which arise as offshoots of the existing ones which meet the lacunæ, whose conversion into blood channels extends the capillaries into fresh areas. This extension of vascular area stops when the stroma becomes more compact which is due to the closing up of the wider lacunæ rather than the increase of cells which are drawn towards the repair of the cast-off layers of sub-mucosa and epithelium. The function of the extravasated leucocytes is to clear the dead and disintegrating red corpuscles and most of them re-enter the blood stream of the freshly formed vessels. During the recuperating phase the white corpuscles are markedly few and those which donot enter the blood, remain in the stroma and may even enter the glands.

I have not succeeded in studying the time and the conditions under which ovulation takes place in Loris, but the examination of the sections of the ovary in the proœstrous period offers some clue as to the factors which help in the extrusion of the egg. The follicular cavity in the peripheral egg becomes greatly dilated on account of the accumulation of fluids, while at the same time the follicular membrane and the stroma surrounding it become thin. The ovary becomes larger at this period owing to the extravasation of blood, which is similar to what takes place in the uterus. The combined pressure of the blood and the liquor folliculi must suffice to extrude the ripe egg; the rupture of the investing membranes being easily effected by their being thinned out. The recuperation of the ovary synchronises with that of the uterus, but for want of complete evidence, it may not be safe to suppose that the processes of ovulation and menstruation go together. Lacunæ in the connective tissue of the ovary appear at the time when it enlarges on account of the increased vascularisation and the causes which produce them are that at the time the proœstrum commences, the tissues become loose and open out just in the same way that the stroma of the uterus behaves during this period. The lacunæ are easily distinguished from the ramifying system of invagination for the formation of fresh ova, by the fact that the latter are lined by the germinal epithelium and tubal eggs are always detected arising from the germinal cells and interstitial cells in the neighbourhood. The connective tissue of the ovary becomes compact after impregnation of the egg and in the sections of the ovary in the different stages of pregnancy, the lacunæ have disappeared and the blood vessels are fewer, and the repair is carried on almost entirely by the connective tissue cells which actively multiply directly in the early stages of fœtal development. I have not noticed the formation of fresh vessels in the recuperation period of the ovary, the walls of the old ones being established by the migrating connective tissue cells which are at first flat, but later become lengthened and partly also by the granular cells in the vicinity of the vessels.

In their recent paper on the *Corpus luteum* of the Monotremata Hill and Gatenby (13) and Marshall (4) have given a complete list of references on the subject of Corpus luteum and I have been collecting material of Loris with a view to study the stages in its formation in relation to the structural changes of the oviduct on the one hand and with the mammary glands on the other and also to follow the history of cell inclusions like Golgi bodies and mitochondria in the successive phases of its growth. As the subject is proposed to be dealt with separately as soon as sufficient material is available, I restrict myself here to a short description of the formation of Corpus luteum which accords with the observations already published. I select only two stages. It has been already stated above that the extrusion of the ovum takes place mainly on account of the pressure of liquor folliculi, aided by that exerted by the extravasation of blood in the regions of theca externa of the graffian follicle. I have not observed the escape of the blood into the follicular space where therefore the clot noticed in the other mammals does not occur in Loris, but the fluid forms a fibrillar matrix. The greater part of the follicular membrane persists and initiates the formation of luteal cells by hypertrophy. The connective tissue cells of both the thecæ become less long and ultimately flat when they escape into the mass of the enlarging follicle cells. Along with the general migration of the theca cells, the blood corpuscles are also borne by the stream and enter the follicular space. A large number of the connective tissue cells derived from the theca externa on reaching the cavity assume a fibrillar character which is the basis of the connective tissue of the Corpus luteum. In the first stage in which the uterus measures 35 mm. across the Corpus luteum is already definitely formed and the cellular modifications can still be followed. Modified and unmodified follicle cells are demonstrable, the latter forming a layer many cells deep and closely adherent to the theca interna as a uniform lining while the former form a loose net-work of cells, appearing very like the structure of lymphatic glands. The chromosomes of these modified cells are irregular strands, with lumps here and there and the nucleoli occur both in the nucleus and the cytoplasm which is richly granular. These luteal cells are three to four times the size of the follicle cells in the lining membrane. When the connective tissue cells enter the follicular space and the meshes of this spongy matrix of cells, some assume the character of luteal cells and others become fibrillar. The nucleus of such cells is greatly lengthened and ultimately loses the staining properties. In the second stage which I have examined, in which the uterus measures 45 mm. and weighs 30.5 grms., the transformation of the cells and the fibres is completed. The thecal investments are thin, the central cavity is occupied by a few fibres and the main mass of the Corpus luteum is formed of greatly enlarged cells with hypertrophied nucleus, a large number of nuclear fragments and deeply staining cytoplasm full of granules. The structure is still spongy and the connective tissue fibres do not form definite bundles, but lie scattered throughout. Leucocytes and red corpuscles of the blood are also met with in the general mass. The Corpus luteum measures $0.4 \times .37$ mm., the luteal cells 20μ while the follicle cells 12μ, each represents the average of 12 cells. There is at this period a general activity of the stroma cells lying outside the thecal investments of the Corpus luteum. In both these stages of the ovary which I have selected for study, the orifice of the graffian follicle through which the ovum escaped, has closed up and as in a future communication I expect to be able to set forth a more detailed description of the growth changes of the Corpus luteum in relation to the connected organs, I hope to be able to refer to the structural modifications of this aperture.

THE SECRETION OF THE UTERINE GLANDS AND THE FOLLICLE CELLS.

The microscopic preparations of the uterus of Loris in the resting or recuperative period show that the cells of the glands are histologically identical with those of the lining membrane of the cavity. The cells are large, slightly columnar, with a clear cytoplasm and basal nucleus. No nucleolus is visible. The chromatin occurs in a frayed condition. During the period of secretive activity, the cloudiness of the cytoplasm obscures the cell outlines and in places where the glandular cells have escaped into the lumen along with the secretion, it is possible to note the occurrence of a nucleolus both within the nuclear membrane and in the general protoplasm. In some cases the number of nucleoli may be two and even three. In Bouin preparations the secretion presents a fibrillar picture and in the material fixed in Zieglwallner, Levi, Schridde and Regaud fluids it is alveolar.

The secretion of the uterine glands occurs normally throughout, but becomes copious during the proœstrum and pregnancy. In the final phases of the proœstrous cycle, the lumen of the glands is filled with the hardened mass, while in pregnancy similar clots of secretion may often be met with in the chorionic vesicles. In the sections treated with Best's Carmine, the whole of the section is suffused with red and in the cells of the glands, red patches are formed near their free ends. This is the case during the proœstrum. These glycogenic areas disappear during the recuperative period both from the secretions and the cells, but manifest in an extended form even in the later stages of pregnancy. As the early stages of the fœtal development were not fixed in Zieglwallner's fixative, I am unable to describe the history of glycogenic formation in those stages and my account refers to periods in which the fœtus has already developed the liver. But still the glycogen in the uterus and in the maternal placenta is marked. I have not been able to ascertain the age of material which, however, I propose to describe in terms of weight and volume. The pregnant uterus fixed in Zieglwallner's weighed 39.5 grammes and measured across 50 mm. and the fœtus had not developed the auditory pinnæ. The chorionic vesicles of the fœtal placenta are already fairly large and are scattered over the entire surface. They open into the placental crypts by a circular orifice, almost surmounting a duct-like prolongation and the cavity of the vesicle as in Galago and Nycticebus is traversed by villous outgrowths. The vesicles, in the nature of store houses, receive the secretions of the uterine glands as they are delivered and show red patches indicative of the presence of glycogen which is not demonstrable in the other parts of the fœtal placenta, except in certain regions of trophoblast where it comes in immediate contact with the orifices of the uterine glands. I have examined the secretion of the uterus in the later stages of pregnancy in which it weighs 89 grammes and measures 45 mm. and the glycogen content is not traceable. It would appear that the chemical nature of the uterine secretion is controlled to a large extent by the resources of the metabolism of the fœtus in the course of its development.

The history of glycogen formation in the liquor folliculi is fugitive. At the time of proœstrum the changes in the histological structure of the stroma in the ovary are parallel with those occurring in the uterus. The follicle cells in this stage show remarkable activity and divide mitotically and the follicular cavity increases owing to the accumulation of the fluids, in those ova which have completed their development and are fit to be released into the fallopian tube. In the sections of the ovary in the culminating periods of proœstrum, stained with Best's Carmine, the greatly distended graffian follicles show the presence of glycogen distributed in a series of faint patches, which also occur in the follicle cells in the immediate neighbourhood throughout the cavity. In the deeper layers of membrana granulosa glycogen is absent which occurs, on the other hand, in the cells of discus proligerus. In each ovary, not more than two or three such glycogen-occurring eggs are met with and in the unripe ones there is no trace of glycogen at all. Similarly, fat globules are entirely wanting in the unripe eggs. The ova when fully mature show the presence of glycogen in greater abundance than either the liquor folliculi or the follicle cells. It is not uniformly distributed, but occurs in isolated fields of irregular outlines or as bands in the cytoplasm of the ovum and they are detectable mainly in the inter spaces of fat globules of both varieties. While for the purpose of glycogenic metabolism of the ovum, there is enough storage of carbohydrate in the body of the egg itself, its presence in the liquor folliculi can be accounted for either on the basis that the follicular cells in the period of proœstrum behaves in its secretory activity like the glandular cells of the uterus and therefore part of their function; or that the ovum in this period of development draws upon this reserve for its glycogenic metabolism.

In a paper on the structure of the ovarian ovum of Loris (14) the present writer has described the formation of fat and yolk in the eggs and has shown that in the elaboration of the former the nucleolus almost entirely takes part, while the latter owes its origin to the activity of the mitochondria as well as the Golgi bodies. It has been noticed that the nucleolar emission is multiple and not infrequently two or even three nucleoli may occur in the protoplasm of the ovum at one and the same time. Those that are extruded during the earlier stages of the maturation phenomena are primarily concerned with the elaboration of fat bodies and in these stages, no glycogen is demonstrable in the ova. At about the time when the chromosomes enter upon the diplotene phase, the first two nucleoli which have formed the large and small types of fat globules are eliminated from the ovum, and a third nucleolar emission takes place. Like its predecessors, it moves about the general cytoplasm in between the fat spherules fulfilling the specific function of glycogen elaboration. While in the first two cases, small fat globules are found both in the centre and the periphery of the nucleoli, showing the mode of their origin, the nucleolus which escapes into the ovum for the last time is entirely free from fat and is surrounded by red patches in sections treated with Best's Carmine. The other patches in the cytoplasm indicate the positions previously occupied by the nucleolus and from which it has shifted in its movement before finally expelled. I am unable to detect any difference in the staining properties of the nucleoli which give rise to the fat spherules on the one hand and that which elaborates glycogen on the other. In both cases, the nucleoli retain their original volume and if there is any change in form it is due to the pseudopodial activity generally believed to occur in them. Even in the follicular cells and in the glandular cells of the uterus, the origin of glycogen is attributable to the nucleolar activity and even in cases where sometimes the stroma shows the occurrence of glycogen, it arises from the nucleolar activity of the interstitial cells. Fat globules do not occur in the liquor folliculi nor even in the follicle cells.

The origin of fat globules in the uterine secretions in the procœstrum and pregnancy is attributed to the degeneration of the decidual cells in the latter case and in the former there is no reliable description accounting for their elaboration. The appearance of fat in the uterine secretions at the time of the procœstrum is easily studied, but in consequence of the infiltration of fat droplets into the placental sinuses the study of their source of origin is attended with difficulties. Now in the first case, minute droplets of fat arise in the body of the cells of glandular epithelia and are delivered into the lumen along with the secretions. Here they run together to form larger spherules. Their elaboration is initiated by the nucleolar agency which, as I have recorded above, manifests at about the time when the cells assume functional activity. Fat sometimes occurs in the submucosa and the underlying connective tissue where it is formed by the nucleolus of the mucous and interstitial cells. They are not released into the secretions which escape into the uterine chambers, but their formation must be associated with the hydrocarbon metabolism of the tissues of the uterus which is heightened in the procœstrum and œstrum. Throughout pregnancy the uterine glands are active and so also the epithelium of the maternal placenta. In the stages of the uterus which I have examined for glycogen, I have noticed the occurrence of fat in the trophoblast where it comes in contact with the maternal wall, in the secretions and loose cells in the placental sinuses, in the cells and secretions of the uterine glands, in the contents of the chorionic vesicles and in the lacunæ and perivascular spaces of the uterus. The presence of fat in the trophoblast and even in the endothelium of the fœtus, is due to the passive absorption of fine droplets from the surrounding nutritive matrix and not to the secretory activity of the cells. At any rate, it is impossible to follow their elaboration in the cells concerned. Turner in his paper on the placentation of Lemurs (15) and Strahl (16) hold the view that the uterine epithelium is secretory and in Loris, the cells of the epithelium are identical in all respects with those of the glands. They are both cubical cells with active spherical nuclei and in the regions of depression the epithelial cells are actively secretory and the surface is covered with a homogeneous mucilaginous investment. Both in the cytoplasm of the cells of this layer and the secretion exuding from its surface droplets of fat occur. In the gland and epithelial cells, fat and glycogen are formed through the agency of the nucleoli which are expelled in instalments from the nucleus. The glands which are present immediately in the mucosa are more active and the coagulum is greater than those in the remoter regions in the uterine folds. The mucosa glands open together through common orifices in the crypts and in the sections, the openings of the distant glands are not easily made out, but there can be little doubt that they also contribute to the nutritive secretions. The fat spherules in the mucosa and connective tissues in the perivascular regions are derived from the interstitial cells which also become secretory as they contribute to the glycogen content of the uterus. The crypts or depressions of the uterine wall receive the villous outgrowths, mostly dendritic, of the allanto-chorion and there is a fairly wide space intervening between the two structures. Towards the head-end of the embryo and also on the sides, the chorion is studded with the vesicles which were first noticed by Hubrecht (18) in Nycticebus and later by Strahl (17) in Galago, and by Hill and Burne (19) in Chiromys. The vesicles lined by the involuted trophoblast and whose cavity is permeated by the villous ingrowths of the same layer, must have a functional importance as is evidenced by the fact that the coagulum of these structures contains both glycogen and fat bodies. These fat spherules are partly derived through this infiltration from the epithelial surface of the uterus but more abundantly from the glandular secretions. A large number of mucosa, epithelial and glandular cells escape into the intervening spaces between the chorionic villi and the uterine crypts and they bear both glycogen and fat to the trophic epithelium of the fœtus and after conveying, they degenerate and form pigment granules.

THE RELATION OF THE CELL INCLUSIONS TO THE SECRETIVE ACTIVITY.

In view of the fact that the successive nucleolar emissions play an important part in the elaboration of important cell constituents, the nucleolus ought to take rank with the Golgi Apparatus and Mitochondria. In the secretive phenomenon of the ovum, the follicle cells, th eglandular mucosa and interstitial cells of the uterus, the nucleolus fulfils a definite function, *viz.*, the initiation of fat globules and glycogen. The succession of emissions is correlated with the sequence of their formation. For instance in the fully mature ovum the fat spherules are already formed and they owe their origin to the activity of the first two nucleoli and in the final phases, the third nucleolus almost exclusively concerns itself with glycogen formation, all the hydrocarbon needed for fat metabolism of the egg being already developed. There is no difference, however, in the staining properties of the fat-forming and glycogen-forming nucleolus in the Loris ovum. In the follicle cells, the fat bodies are not formed and if any were to occur in the liquor folliculi of Loris, they are due to their infiltration from the egg. The nucleoli of the follicle cells are therefore exclusively occupied with the elaboration of glycogen. Now in the case of the glandular mucosa and interstitial cells of the uterus, fat and glycogen are separately evolved by two successively extruded nucleoli and therefore in their behaviour they correspond with those of the ovum. In all cases where glycogen formation can be followed with accuracy, it is noticed that the area of cytoplasm immediately surrounding the nucleolus concerned, there is a deposit of fine granules which stain red with Best's Carmine and those formed first near the nucleolar membrane in the form of a zone are pushed outwards as fresh ones develop. The amount that could be formed in any particular area is limited as it must depend upon the available carbohydrate in the cytoplasm of that particular region. The nucleolus having given rise to a glycogen patch nearly three times its diameter, next pushes forward to another area only in the ovum and not in the other kinds of cells which have been studied where it is expelled. It is not unusual to find two or three glycogen districts in the body of a full-grown ovum from which also the nucleolus is finally eliminated, like the fat-forming nucleoli. By the time this last nucleolus arrives in Cumulus proligerus, its predecessors will have disintegrated and absorbed by the follicle cells which meet out a similar fate to the latest arrival. The extruded nucleoli of the gland, mucosa and interstitial cells are seized by the wandering leucocytes which eliminate them.

As described in a previous paper (14), the behaviour of the Golgi apparatus and of the two kinds of mitochondria in the formation of yolk in the ovum of Loris has been described, it is unnecessary to refer to them here. But it must be recalled that after the elaboration of yolk no part of the Golgi apparatus is shed from the ovum, this is particularly because no part of the contents of the ovum escapes from its body surface.

In the follicle cells, the Golgi bodies occur in the form of a nuclear cap, composed of three or four rodlets which are reticulated. This is easily demonstrable in silver nitrate and Mann-Kopsch preparations. In the glandular, mucosa, interstitial and epithelial cells of the uterus, the apparatus forms a more compact net-work in which the number of rodlets cannot be counted. There is a definite polarity in their location in the follicle cells, glandular, mucosa and epithelial cells always occurring on the free surface. The nucleus lies as has been noticed by previous investigators of this subject on the far side of the free surface. The mitochondria are only made out with difficulty in the follicle cells and where discovered, they occur in the form of dust at both poles of the nucleus. In the other cells enumerated above, they are fine granules aggregate at the ends of the nucleus with a thin layer on the sides also. The onset of the glycogen activity of the cells which takes place simultaneously with the general secretory phenomenon is indicated by the formation of granules and a cloudiness of the cytoplasm. These granules preponderate at the far end of the cell body. In this stage the only way of distinguishing the mitochondria from the secretory granules, is the size and staining property. The mitochondria give up their position and become distributed throughout the cell mass. Either on account of the mechanical pressure exerted by the newly formed granules, or because of their own spontaneous activity, the Golgi apparatus becomes loose and forms a close cap over the nucleus. I am unable to state whether the Golgi rods take part in the elaboration of the secretory granules or even mitochondria, but it is clear that they play no rôle in the elaboration of glycogen which is developed like the fat spherules almost exclusively by the nucleolar agency. The first nucleolar emission,—a nucleolus being absent from the cells in the glands, mucosa and epithelium during the resting period, heralds the first phase of the secretory cycle, during which the fat bodies and granules are established and on the expulsion of this, the second nucleolus is extruded which concerns itself in the formation of glycogen. During all this period, the mitochondria keep changing their position owing to the movement of the general cytoplasm consequent upon the appearance and arrangement of new secretory bodies. This must also be the cause of the shifting forwards of the nucleus which carries before it the Golgi apparatus and such portions of mitochondria as may lie between it and the free surface of the cell. The release of the secretion from the cell body is in the nature of the rupture of the cell outline which delivers it into the lumen or cavity. A few Golgi rodlets, mitochondria and the secretions including fat globules escape. This is applicable to the uterine gland cells, mucosa, interstitial and epithelial cells. But I have not noticed such escape of Golgi batonetts from the follicle cells whose wall is more resistant. The delivery of secretions into follicular cavity perhaps takes place in the form of transfusion. The glandular cells after the pouring out of secretions undergo shrinkage, when the nucleus returns to the base and brings back those Golgi rodlets which have not been expelled. They re-arrange and multiply by splitting and form a compact dense mass. The mitochondria readjust themselves in the characteristic position. It frequently happens that during great active phases of the glands, some of the cells themselves, especially the non-cubical or flat ones, escape into the lumen. Such cells after retaining for some time their definite shape and their inclusions, degenerate and if they occur in the mucosa, are seized by the leucocytes and are eliminated or if they occur in the cavity of the uterus or lumen of the glands, disintegrate and form melanin granules. During the procestrum, great areas of the epithelium are shed and their cells degenerate and stain very deeply with hæmatoxylin. Even otherwise they form dark masses. I must state at once that the observations which I have recorded here on the behaviour of cell inclusions in the Lemur are in accord with the results obtained by the previous investigators and in the case of the glycogen formation, I attribute it to the nucleolar agency.

SUMMARY.

The South Indian Loris breeds twice in the year. The number of diœstrous cycles is limited to two. The proœstrum is characterized by a very slight sanguineous discharge and swelling of the external genitalia. During this period the testes of the male descends into the groin and produces swellings externally. The menstrual cycle may be divided as in the case of Primates generally, into (1) The period of rest; (2) The period of growth; (3) The period of degeneration; and (4) The period of recuperation. During the period of growth, the congestion of the epithelium is localized, being confined to the anterior division of the uterus, while hyperplasia of vessels takes place practically all over the stroma and immediately below the mucosa. Extravasation of blood from the ruptured capillaries and the delivery of the secretions of glands together with pieces of glandular tissue take place during the degenerative period. The epithelium is shed over the whole of the anterior cornu of the uterus, while none of these changes occur towards the vaginal end. The changes taking place in the stroma and the re-establishment of the epithelial lining in the case of Loris are in accord with observations of Heape on Semnopithecus (Pithecus) entellus. The walls of the capillaries and arterioles are formed by the interstitial cells, and new vessels are established by the outgrowths of capillaries which meet those lacunæ which have not closed up.

It has not been possible to determine whether ovulation synchronizes with menstruation. During proœstrum the

ovary swells out owing to the congestion of the blood vessels, the finer capillaries breaking out. Lacunæ filled with Coagulum also appear in the stroma. The repair of the ovary is noticeable in secretions taken during pregnancy.

The formation of Corpus luteum has been studied in two stages of advanced pregnancy. The luteal cells are derived from the follicle cells as well as those of the external and internal theca. The connective tissue matrix of Corpus luteum which forms a very loose frame-work is derived from both the thecæ. The blood clot noticed in the follicular space of other mammals does not occur in Loris in which there is no extravasation of blood into this cavity.

The epithelial cells are plump and cubical and are histologically and therefore functionally identical with the glandular cells. The secretion occurs normally throughout, but stimulated to greater activity during the procœstrum and pregnancy. Glycogen occurs in one or two patches in the fully grown ovum in the liquor folliculi, in the gland, mucosa, interstitial and epithelial cells during procœstrum and the early stages of pregnancy. It is elaborated in the cytoplasm by the activity of nucleolus in every case. The nucleolus according to the order of emission has a dual function ; the one extruded first elaborated fat globules (except in the follicle cells), and that extruded last concerns with the formation of glycogen. The formation of fat and glycogen does not take place simultaneously.

The Golgi apparatus and mitochondria do not apparently take any part in their formation. They are disturbed from their normal positions during secretory activity of these cells and when the secretion is released, some of the Golgi rodlets and mitochondria (except in the follicle cells) are extruded owing to the rupture of the cell membrane at the surface. This is helped by the movement or change of position of the nucleus itself which shifts to the free margin during the release of secretion. The remaining rodlets by multiplication, reconstruct the entire apparatus and the mitochondria regroup themselves in the polar regions and sparsely on the sides of the nucleus when the cell returns to the quiescent condition.

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LETTERING.

bc.	..	Blood corpuscles.
bv.	..	Blood vessel.
C.	..	Uterine chamber.
Cap.	..	Capillary.
cv.	..	Chorionic villi.
ep.	..	Degenerate uterine epithelium.
etc.	..	External thecal cells of Corpus luteum.
f.	..	Fat bodies.
fc.	..	Follicle cells in a state of conversion into luteal cells.
fm.	..	Follicle cells in a state of mitotic division.
fn.	..	Nucleolus producing fat.
g.	..	Golgi bodies.
gc.	..	Extruded glandular cells.
ge.	..	Glandular epithelium.
gl.	..	Glycogen.
glc.	..	Glycogen-bearing gland cells.
gn.	..	Nucleolus producing glycogen.
itc.	..	Internal thecal walls of Corpus luteum.
L.	..	Lacunæ in the region of submucosa which by widening produce the shedding of layers of cells in the period of menstruation.
l.	..	Lacunæ in the stroma which give rise to fresh blood vessels in the resting period.
lc.	..	Luteal cells.
m.	..	Mitochondria.
mc.	..	Migrating stroma cells re-establishing the mucosa and submucosa.
Mm.	..	Worn out sub-mucosa extruded with the menstrual clot.

n.	Nucleolus.
pv.	Placental villi.
s.	Glandular secretion carrying away before it fat, golgi rods, mitochondria and nucleolus.
sc.	Epithelial cells in secretory activity.
sc′.	Stroma cells in mitotic division.
sg.	Secretory granules.
sgl.	Secretion in glandular cavity containing glycogen and fat.
sm.	Sub-mucosa.
st.	Stroma and connective tissue cells.
t.	Trophoblast.
tf.	Thecal fibres of Corpus luteum.
ue.	Uterine epithelium.
v.	Chorionic vesicle.
vac.	Vacuoles in the sub-mucosa.
Vv.	Villi of the vesicle.
wc.	White corpuscles.

EXPLANATION OF FIGURES.

Fig. 1. These have been drawn from Levi preparation and details from Mann-Kopsch material have been added. 1–4. Glandular cells of the menstruating uterus of Loris in four stages of secretory activity in which the history and the part played by the Golgi apparatus and mitochondria in the elaboration of secretions can be easily followed. 2–7. Follicle cells. In 3 and 4 two nucleoli are seen, one of them marked *n* is concerned with the production of glycogen and the other elaborates fat. Similarly in 6 and 7.

Fig. 2. Section of Corpus luteum passing through the surface, hence looks solid. The external and internal thecal and follicle cells contribute to the formation of

luteal cells and the fibres are seen radiating towards the centre from the theca. The ovary belongs to a gravid female Loris. Mann-Kopsch preparation (seven days in Osmic acid). The details of cell contents have been omitted from the figure.

Fig. 3. The graffian follicle with the ovum of Loris at the time of menstruation. There are three nucleoli in the ovum, two fat-producing and one glycogen-producing type. Zieglwallner fixation followed by Best's Carmine. The Golgi body, mitochondria and fat in the liquor folliculi have been added from the second ovary of the same specimen fixed in Mann-Kopsch.

Fig. 4. Section of the uterine glands of a menstruating Loris. Zieglwallner fixation followed by Best's Carmine. The composition of the glandular secretion and how it clogs the entire cavity can be noticed.

Fig. 5. Structure of the resting stage of the uterus of Loris which has passed through the diœstrous cycle. The epithelial cells retain secretory activity and the lumen of the glands is filled with secretory Coagulum. Levi fixation.

Fig. 6. Section through the anterior region of the uterus of Loris in proœstrum. The lacunæ which arise between the sub-mucosa and stroma have widened so as to cause the dehiscence of the layers. The vacuoles which produce the degeneration of the mucosa cells are seen. The great activity of the stroma cells and their migration towards the dehiscing surface are seen. The capillaries at Cap. may be noticed to give off outpushings which by coalescence with the lacunæ (1) in the stroma, establish fresh blood vessels in the place of the ruptured ones. The epithelial layer of the uterine glands has shrunk considerably, the cells having discharged the secretion together with effete cells. Zieglwallner fixation followed by Best's Carmine.

Fig. 7. Section through Chorionic vesicle and a portion of the fœtal placenta of Loris. The vesicular villi

in some regions form an anastomosis and the composition of the vesicular contents is miscellaneous. In this stage the glycogen is confined to the vesicle and fat occurs only rarely. Zieglwallner fixation followed by Best's Carmine.

Fig. 8. Section of the upper region of the uterus of Loris in diœstrum. At 'a' the entire glands have been washed away and at 'z', the glands are shown in different stages of detachment from the sub-mucosa. The great activity of the cells in reconstructing the glands can be noticed at 'a' where the cells are dividing. In the proœstrous phases, the same cells divide mitotically. The migration of the stroma cells for the formation of the mucous and sub-mucous epithelial layers is also noticeable. The formation of vacuoles in the glandular cells and in the mucosa is identical and is the cause for their dehiscence.

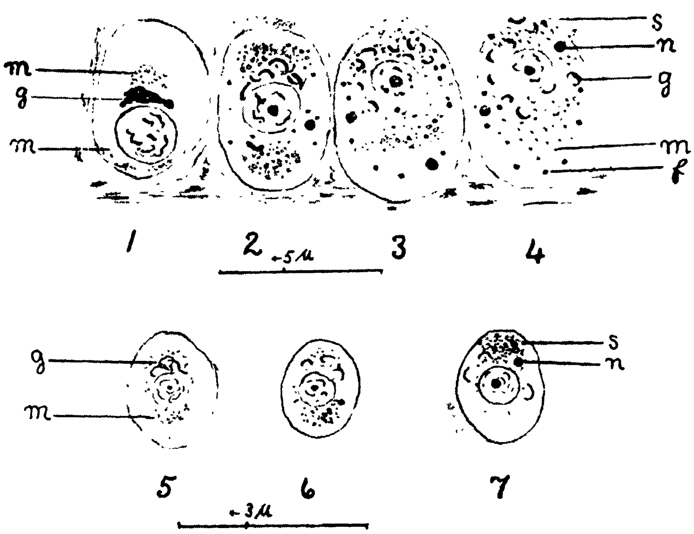

Fig. 1

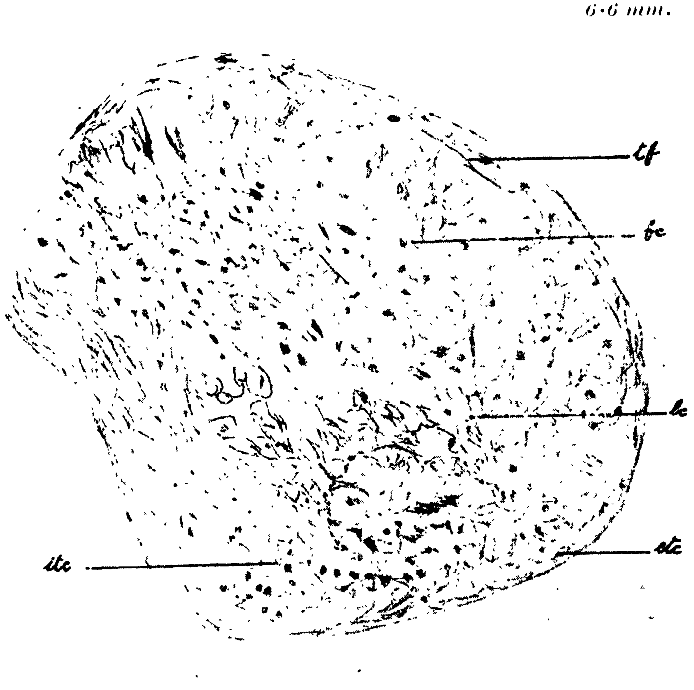

Fig. 2

6·6 mm

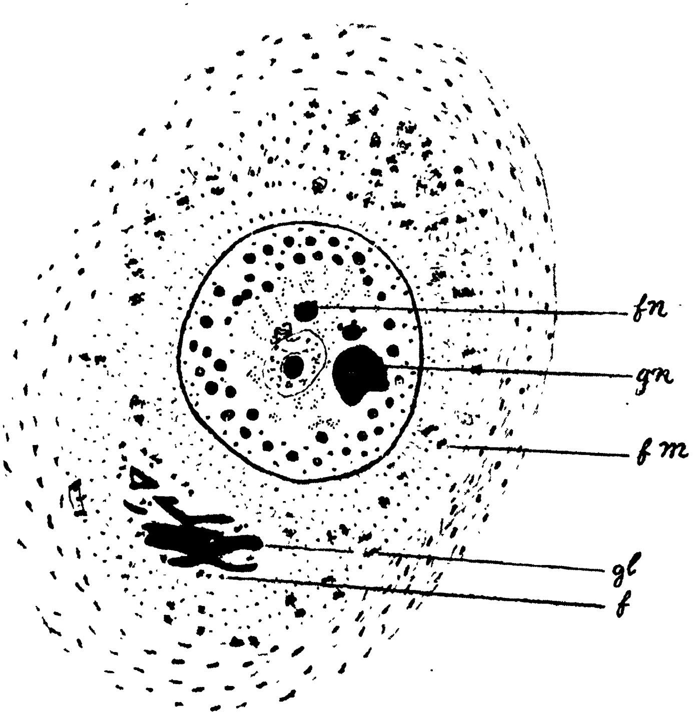

Fig. 3

1 mm.

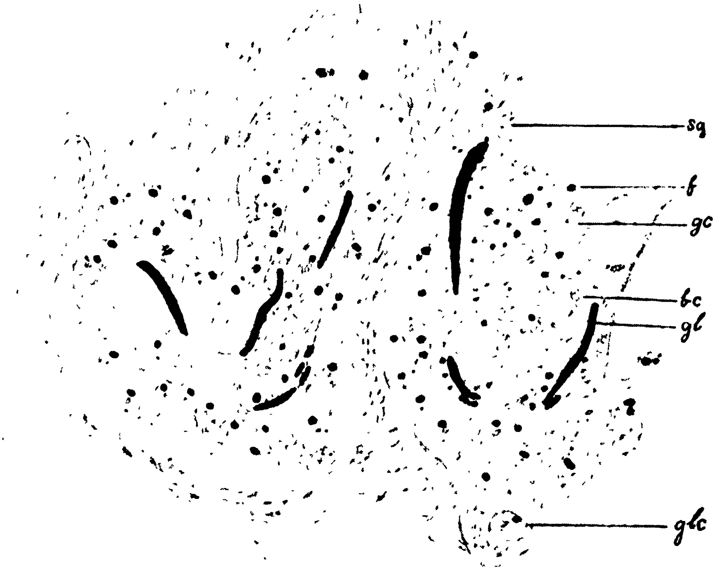

Fig. 4

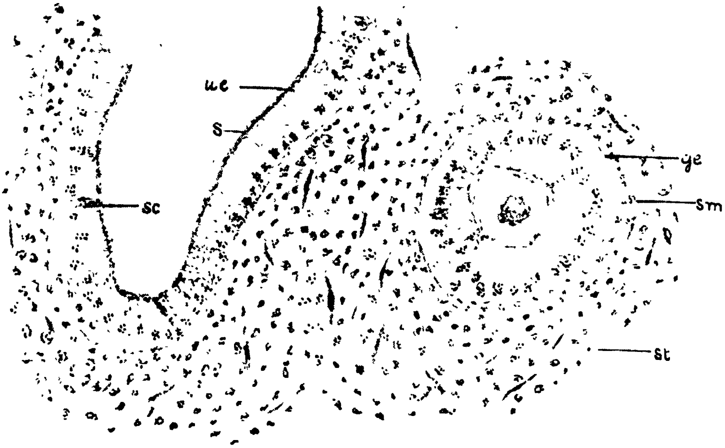

Fig. 5 ×65

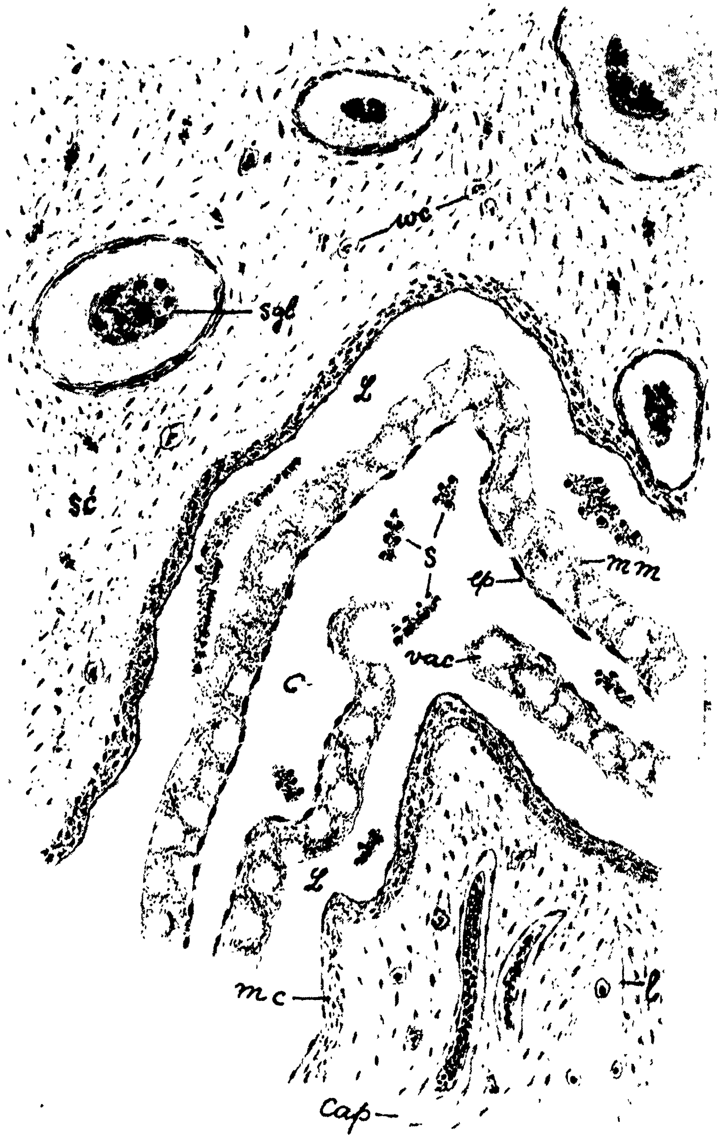

Fig. 6 ×100

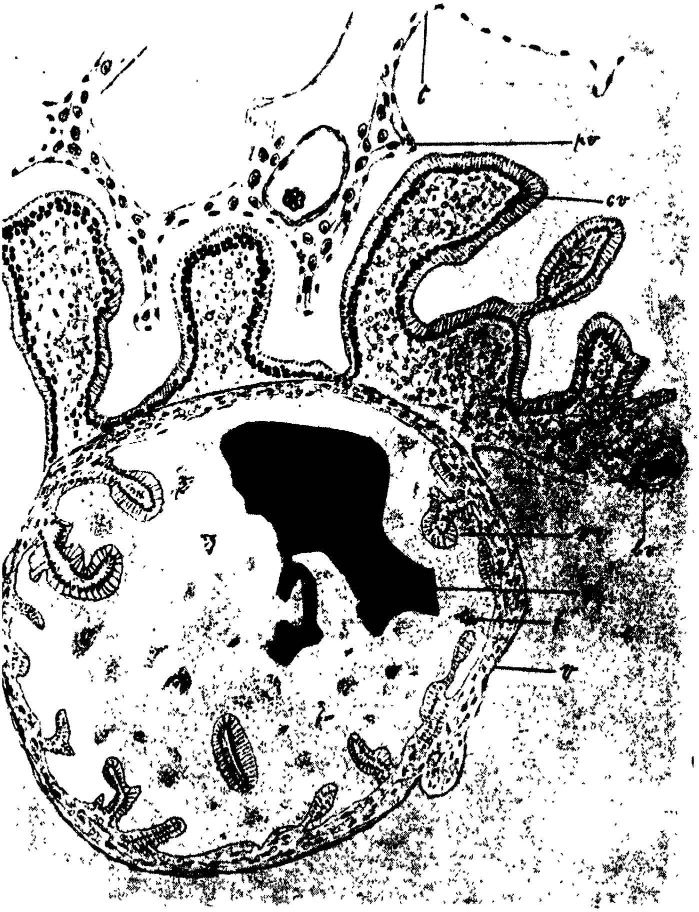

Fig. 7 ×65

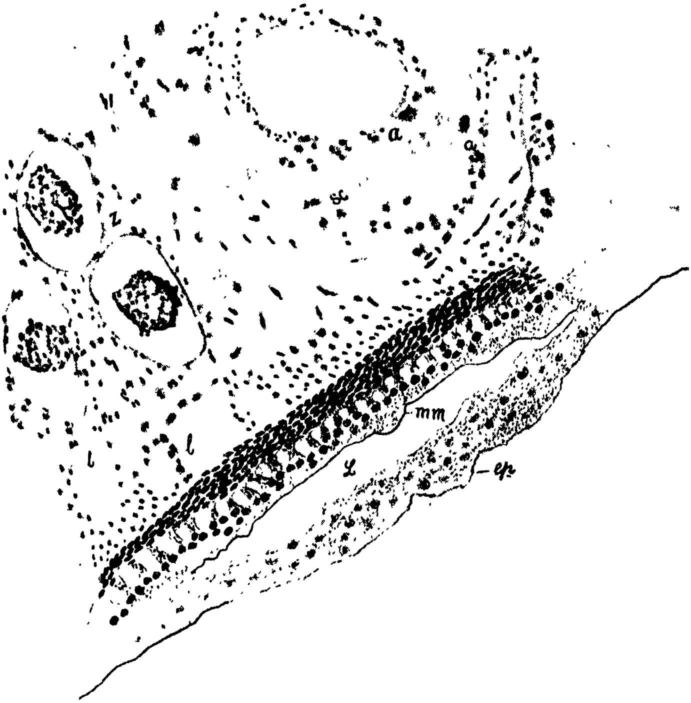

Fig. 8 ×100

THE GYMNOPHIONA OF MYSORE.

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The *Gymnophiona* (*Lissamphibia*, *Coeciliae*, *Apoda*) constitutes a very interesting group of Amphibia exhibiting many primitive characters. Their habits, structure and development are but scantily known. They are characterized by an elongated body exhibiting circular rings, the absence of limbs, a rudimentary tail (which may be entirely wanting) and dermal scales embedded in the skin. The animals are burrowers and the large quantity of mucus secreted by the skin assuredly aids them in their progression.

The group contains twelve genera which have a curious distribution. They are generally restricted to the Neotropical, Ethiopian and Indian regions, being, however, entirely absent from Madagascar. Three genera are represented in India,—*Ichthyophis*, *Uræotyphlus* and *Gegenophis*. The work of the Sarasins in 1890 (*Ergeb. Naturw. Furchen. auf Ceylon*, Bd. 2) who were almost the first to describe extensively the anatomy of *Ichthyophis glutinosus* from Ceylon, was the starting point of numerous memoirs on the anatomy and development of the *Gymnophiona*. The works of Brauer, Marcus, Kuhlenbeck, Peter and Semon are amongst the more important. Still, our knowledge about the bionomics of this interesting group of animals is very meagre.

It is generally known that *Ichthyophis* and its Indian congeners are found in the tropical forests of the Western Ghats, the Khasi Hills and other mountain ranges of India, Burma and Ceylon. Probably *Ichthyophis* is the most common of these three Indian genera. It has two species : *I. glutinosus* and *I. monochrous*. The former, which is the more common of the two, is characterized by the presence of a bright yellow lateral band. The dorsal surface is dark brown in colour and the ventral surface is pale brown. The distance between the two eyes in this animal equals the length of the snout. The species attains a length of 15 inches. *Ichthyophis monochrous*, on the other hand, does not possess this yellow lateral band, its colour being steel blue above and pale yellow beneath. The head is broader and consequently the distance between the two eyes greater than the length of the snout. Though Boulenger mentions the length of this form as 13 inches, we have in our possession specimens much larger, in fact, even larger than *I. glutinosus*. A well-grown specimen may attain the length of 16 inches.

In October 1931 the staff and the students of the Zoology Department, Central College, while on an excursion, collected a few specimens of *Ichthyophis glutinosus* from Kottigehar, about 200 miles from Bangalore in the Western Ghats. This was the first time they were reported from Mysore State, though this is not a fact of great importance as the Western Ghat range continues along the western boundary of the State. Being interested in the gametogenesis and other allied studies of this animal, we recently paid another visit to the area with a view to collect more material and to study the habits of the species in general. In this we were very successful, being able to collect a large number of adults and young ones. We have brought home some specimens alive and are trying to rear them in the laboratory providing the animals an environment as natural as possible. But we find this a matter of considerable difficulty as the animals in confinement tend to become cannibalistic. The larger and more powerful ones nibble away the skin and muscles of the younger larvæ. One morning we found half a dozen larvæ dead due to the numerous injuries inflicted on their bodies by the older animals. We have, as a corrective measure, segregated the older animals.

The adult *Ichthyophis glutinosus* occurs in a variety of situations. Specimens have been collected from the roadside, below boulders and fallen tree trunks, from old and dilapidated houses, under hayricks and in the forests themselves in rotten timber and under decaying vegetation. The local peasants call it "Hithalu Mandla" (Backyard snake) on account of these animals being not infrequently found under haystacks and piles of fire-wood stored in the backyard. The local coolies and farmers, when they encounter these animals in their processes of clearing the forests for converting them into coffee, tea and cardamom plantations, destroy them in large numbers believing them to be snakes.

Ichthyophis is a burrowing animal and its entire organization is excellently adapted for this habit. The long snakelike body, the absence of limbs, the well-developed and compact skull and the large quantity of mucus secreted by the glands of the skin are the more important modifications consequent on this fossorial habit. *Ichthyophis* is capable of burrowing not only by its anterior end but by its posterior end as well. The anus, which is a longitudinal slit, is subterminal and dorsal to it, the cylindrical body ends in a sharp point, which must undoubtedly aid the animal in burrowing by the hind end. But it seems to us that the burrowing capacities of *Ichthyophis glutinosus* are, however, limited and are exercised only when the earth is soft, moist and yielding. During the drier months of the year and in dry situations, the animal tries more to hide under stones and rotten wood than to burrow.

It is very interesting to note that while the young one lives in water, the adult is rarely, if ever, found in this element. If forcibly thrown into it, the animal swims about actively with horizontal undulations of the body, very much like a snake and rapidly seeks the nearest piece of land. Prolonged and forced immersion in water causes death by drowning.

It is curious to watch *Ichthyophis glutinosus* move on land. On moist ground and amidst wet leaves and grass it moves about freely and it is indeed difficult to secure the animal in such situations. The animal slips away and lies motionless underneath the leaves, the dark brown body harmonising with the rotten vegetation. This is distinctly a reptilian habit. Even an experienced collector will miss some specimens, which slip out of the hand easily due to their great muscular power and their slimy secretion. If an animal is carefully wiped with a piece of cloth and placed on a dry table, it appears to be helpless, hops about in great distress and lies still after a time. In this condition, the skin is dry and glistening and there is no trace of any mucus secretion. Probably the activity of the glands is governed by the condition of the soil, the glands being of use only in a moist environment.

Ichthyophis is harmless and can be handled with great safety and ease. If roughly treated or irritated, however, the skin exudes quantities of a creamy coloured fluid which emits a strong smell of musk and tobacco. Probably this has poisonous qualities, but it has no appreciable effect on the human skin. The same phenomenon is noticed when the animal is either chloroformed or dropped into rectified spirits.

The tentacle is an organ of great significance in the *Gymnophiona*. Its position on the upper lip is of systematic importance. It has been thoroughly examined in *Ichthyophis* *glutinosus* by the Sarasins and more recently by Englehardt (*Jenaische Zs. Naturw.* 60, 1924) and fully described by them. It is a conical structure found in the maxillary groove and protruded by turgescence due to the flow of blood into it. When the animal is moving undisturbed the tentacle is protruded and retracted at regular intervals of about a second. When it is handled roughly, however, it becomes exceedingly vicious, biting savagely and the tentacle is seen protruding and retracting with great rapidity: when dead, the tentacle invariably is in an extended condition, lying limply on the side of the snout.

Ichthyophis is essentially a solitary animal. We have never come across more than one individual in a place. In captivity, however, the animals tend to huddle themselves in a tangle. This is especially so of young ones.

Ichthyophis glutinosus, according to the Sarasins, breeds at the onset of the monsoon and the eggs are laid by the side of the water in a burrow. The eggs are fairly large and about two dozen of them are laid at a time. The female coils round the egg mass and protects it from other burrowing creatures. The most interesting part of the life-history is passed through within the egg membrane where the embryo develops three pairs of external gills and grows at the expense of the large quantity of yolk found in the egg. The embryo hatches out when it is surprisingly long, nearly 6 cms., by which time the external gills are lost but on either side a single cleft, the spiraculum, is present.

With all our efforts, we could not obtain the eggs of *Ichthyophis*. But a large number of larvæ is in our collection. The smallest is about 6.5 cms. in length. Many of these were collected in the tiny brooks that run along the hill slopes at Kottigehar in the coffee and the cardamom plantations. The larva of *Ichthyophis* is a very interesting animal. It has a smooth skin and a tiny tail fin. It breathes air and comes to the surface of water occasionally for the purpose. The young larva does not burrow but occurs in little puddles of water along the brooks on the hillside. Correlated with this free-living habit are the eyes which are better developed in the larva than in the adult, where due to the fossorial habit which the latter have assumed, the eyes have suffered a degeneration which is maximum in the Indian genus *Gegenophis* where the eyes are beneath the cranial bones.

Probably correlated with the steep hillsides where they occur and with the rapidity of the streams, the larvæ have developed another curious structure. The lips are tumid and thick reminding us of some of the allied structures found in certain hill stream fishes. We are not able to say whether the structures are of use to the animals in making them cling to the substratum or to some foreign object to prevent being washed down the stream but it is interesting to note that the young larva is not a burrower and must possess some means by which it averts the danger of being washed down stream. The thick lips are provided with very sharp rows of teeth which line their margin.

About the food of these animals we are not able to say much at present. It has already been mentioned that in captivity, at any rate, the animals tend to become cannibalistic killing their weaker and younger brethren. We have been feeding the animals on termites and earthworms in the laboratory. The latter they devour with great avidity, for the animals swallow live earthworms as a python does its prey, the whole process taking not more than a few minutes. One of the planters complained to us that the animal destroys the cardamom crop breaking open the fruit but we doubt such capacities on the part of the animal. While the small numerous teeth can be used for nibbling soft objects, they are, it appears to us, incapable of doing such active damage. We shall report about the food of these animals after making further observations.

The other species of *Ichthyophis* (*I. monochrous*), we were not able to collect at Kottigehar. But two magnificent specimens were collected by the students of the Zoology Department at Perambikulam in 1930. Messrs. A. Narayan Rao and L. S. Ramaswami who were in charge of the expedition inform us that the animals were found in the hollows of rotten bamboo plants.

Another point of some importance concerns the breeding seasons of the two species of *Ichthyophis*. An examination of the testes of the two species collected at about the same time in the year (October) reveals an interesting feature. While the testis of *Ichthyophis glutinosus* is active and clearly indicates spermatogenesis in progress, the locules of the testis of *I. monochrous* are empty but for a few residual spermatogonia. Probably the breeding seasons of the two differ.

Further observations on the habits of these interesting animals will appear later.

THE CRANIAL ANATOMY OF *GLYPHOGLOSSUS MOLOSSUS* (GÜNTHER).

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In a previous paper (10) the cranial osteology of the endemic Engystomatid genera, *viz.*, *Cacopus*, *Kaloula* and *Microhyla*, was reported with the object of estimating the correct position of this presumably primitive group of Anura. A large number of primitive features in the organization of these three narrow-mouthed toads has been described. The object of this paper is to place on record the salient features in the cranial osteology of the interesting Engystomatid, *Glyphoglossus molossus*, and to note if there are any points of difference or comparison between this and the other three genera previously described. It is to be noted, however, that *Glyphoglossus* is not indigenous to Mysore and therefore the study of it becomes all the more important in establishing the relationship of the group Engystomatidæ as a whole. A single specimen of *Glyphoglossus* was secured by Boulenger (1) from Irrawady delta and Pegu, which seem to be its natural place of occurrence. Specimens have also been reported from Siam.

Among the earliest workers on the cranial osteology of Anura, mention must be made of Gaupp (5) whose 'Anatomie des Frosches' is an invaluable aid in the study of Anuran osteology. Recently, however, Dr. Villiers has studied the South African Brevicipitidæ and the aglossal anura chiefly from the aspect of the cranial characteristics. In the Brevicipitid *Cacosternum* (16) Villiers recognizes the predominating Ranid features and remarks that 'there is however very good reason to believe, that *Cacosternum* is a Ranid as well.' Similarly M. Smith (11) after a careful scrutiny of the skulls of *Phrynella* and *Kaloula* with regard to the differences between the palatine and the vomer, has since abandoned treating them together. Further, in a single genus itself as noticed by Parker* for *Microhyla* the palatine is present in some while wanting in others. The absence of the palatine has been observed in *Microhyla rubra* by me.

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* See *Bull. of the Raffles Museum*, Singapore, No. 3, April 1930, p. 122.

I am indebted to Prof. A. Subba Rau for a fairly adult specimen of *Glyphoglossus* from his collection, for which act of kindness I am thankful to him. My warmest thanks are due to Prof. C. R. Narayan Rao for guidance and direction.

The head was decalcified in 70 per cent. alcohol containing 1 per cent. nitric acid. Sections 10 microns thick were cut and stained in Bismark brown, picro-indigo-carmine, Hæmalum-eosin and Mallory.

At the outset it must be pointed out that *Glyphoglossus* stands apart from the other members of the group Engystomatidæ in very many features. Both the prenasal cartilages, the superior and inferior, are present and support the premaxillæ.

THE OLFACTORY CAPSULE.

The cartilaginous framework of the nasal region is simple and possesses the characteristic structures described by Gaupp for *Rana*. However, from the cartilago obliqua depends the plica and the characteristic Gauppian wulste is absent. A vestigial recess sacciformis may be noticed. In *Cacosternum* (16) where a well-developed recess is present the septomaxillary forms a capsule for it. But, in forms like *Phrynomerus* (15) and *Glyphoglossus*, since the recess is vestigial the septomaxillary bears no relation to it. Whether the septomaxillary is separated from the superior lamina or not, is not possible to be made out in my sections since my preparations do not show it clearly on account of long preservation in alcohol. At any rate the position of the septomaxillary and the vestigial nature of the recess could be easily made out. The other features are exactly as those described by Gaupp for *Rana*. The cavum inferius bears a thickened part towards the septum nasi which has been compared with the organ of Jacobson. The olfactory nerve innervating this part of the nasal organ passes through a groove or canal in the septum nasi. This feature is, however, peculiar to *Glyphoglossus* and not noticed in *Kaloula*, *Microhyla* and *Cacopus*. Further the septum nasi is extraordinarily thick in *Glyphoglossus* and unlike *Cacopus* no trace of ossification can be noticed in it.

In fact a feature of difference which is apparent at the first sight between *Kaloula* and *Glyphoglossus* is the thickness and the passage of the nerves in the septum in the latter, while in the former the nerves run in close companionship with the glandula nasalis medialis. At about the same region in *Glyphoglossus* the thin investing nasals make their appearance. In a slightly posterior region the nasals are large and they never extend laterally towards the maxilla. Even the planum terminale which is thick and short, is uncovered by the nasal in which feature *Glyphoglossus* differs from *Microhyla* and resembles *Rana*.

It is to be remarked, however, that the cavum inferius opens either directly into the buccal cavity or through the intervention of a separate chamber, called the prechoanal sac. Both these features are noticed in the South Indian Engystomatidæ as already reported. In the tadpoles of *Cacopus* the choanæ open into the prechoanal sac in which character they resemble the tadpoles of the South African *Phrynomerus* (15), and when they assume adult conditions the choanæ bear no relation whatsoever to the vestigial prechoanal sac. On the other hand, the tadpoles of *Microhyla* and possibly those of *Kaloula* also, possess no anlage of a prechoanal sac, while in the adults of these examples and also of *Phrynomerus* (15), the cavum inferius opens into two sacs which have been compared to the buccal division of the organ of Jacobson, and these sacs ultimately open into the buccal cavity. While these relationships of the opening of the narial chambers are so complicated in these examples, in *Glyphoglossus*, it is extremely simple. The cavum inferius opens directly into the buccal cavity (see Fig. 1) and it is not possible to say if it opened into an anlage of a prechoanal sac in the larval conditions since I have not been able to study the tadpoles. In possessing no prechoanal sac therefore, *Glyphoglossus* diverges totally from its South Indian and South African congeners and resembles *Rana*. But in *Rana* the eminentia olfactoria is flat and is unsupported

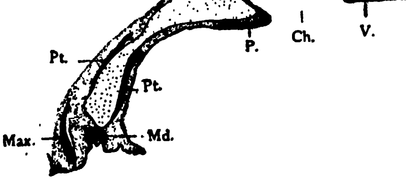


Fig. 1.

Transverse section of *Glyphoglossus* in the region of the choana.

by a cartilaginous axis; in *Glyphoglossus* the eminentia is thick and supported by broad cartilaginous axis which is an extension of the solum nasi.

At the base of the solum nasi the vomer makes its appearance and unlike the Brevicipitidæ and *Microhyla* no extension of the vomer seems to embrace the choanæ in *Glyphoglossus*. The antorbital cartilage is invested by the palatine near the choanal end and towards the maxillary is noticed the pterygoid bone on the dorsal aspect of the cartilage. Moreover towards the recess lateralis also, in the antorbital region and also where the antorbital cartilage unites with the tectum nasi another investment is noticed similar to the pterygoid investment. In the sections taken in the hinder region, it is noticed that this ventral investment joins the pterygoid bone and remains as an internal investment of the pterygoid cartilage. Such an investment I have not noticed in the South Indian Engystomatidæ that I have examined.

The frontoparietals appear just when the choanæ commence to disappear from the sections. They are very well developed and are closely apposed, supporting thereby the statement of Boulenger that the Engystomatidæ are devoid of a fontanelle. But Villiers describes the presence of a frontoparietal fontanelle in most of the South African forms.

The ossification in the ethmoid region is extremely feeble. It may almost be said that the os en ceinture is absent from my specimen of *Glyphoglossus* while the extensive ossification in the ethmoidal region is greatly manifest in *Cacopus* and *Kaloula* and this abbreviation is noteworthy in *Glyphoglossus*. Figure 2 shows the frontoparietals, the three pieces of cartilage dorsally and a large one ventrally,—all the four being derivatives of the trabeculæ. This ventral trabecular derivative divides the os en ceinture into a right and a left half in the South Indian Engystomatidæ. Since the ossification is itself feeble in *Glyphoglossus* such a division is not possible to be made out. Except for two patches of ossification in the cartilage on either side of the brain in this region, no other ossification can be noticed.

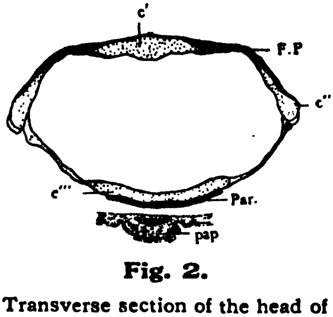


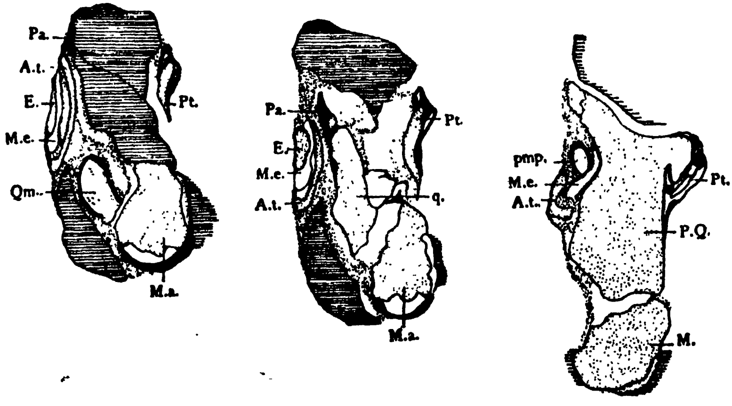
Fig. 2.

Transverse section of the head of *Glyphoglossus* in the region of the frontoparietals.

Such a feeble ossification should not excite surprise since no sphenethmoid or os en ceinture is noticed in the case of *Probreviceps* (20).

THE EAR REGION.

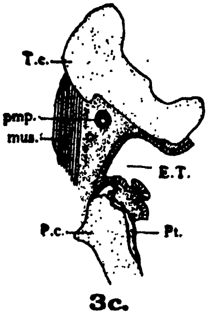
The otic region presents certain peculiarities which I have not noticed in the other Engystomatid examples that I have examined. The occurrence of a hidden tympanum and the 'extraplectral' cartilage and also the incomplete annulus seem to be a distinguishing feature of the group Engystomatidæ, though in a Ranid example *Arthroleptella* (13) Villiers has noticed the presence of an incomplete sickle-shaped annulus tympanicus.



3. 3a. 3b.

Figs. 3—3c.

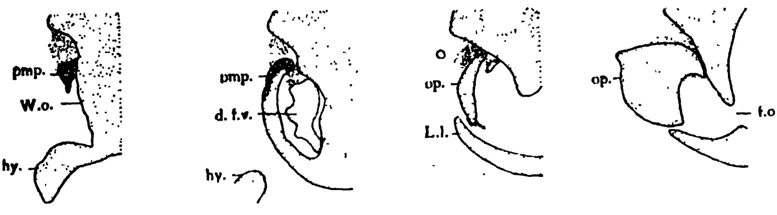
Transverse sections of the middle ear region and associated structures of *Glyphoglossus*.



3c.

Three Figures (3, 3*a* & 3*b*) are drawn to represent the middle ear and the associated structures. In the region where the extraplectral has made its appearance a sickle-shaped annulus tympanicus can be seen. Moreover dorsal to the annulus, the paraquadrate ossification can also be seen. The pterygoid which is to a side is noticed to invest the pterygoid cartilage. The quadratomaxillary which in previous sections is completely osseous is seen in this region (Fig. 3) investing the quadrate cartilage. Soon, the paraquadrate is seen to invest the extended quadrate cartilage and the quadratomaxillary has disappeared from the sections (Fig. 3*a*). The last Figure (3*b*) shows the union of the pterygoid cartilage and the quadrate. The figure also shows the ventral end of the annulus tympanicus, the small middle ear and the pars externa plectrum. Ventral to this pterygoquadrate cartilage is the Meckle's cartilage. The dermarticular investment is absent from sections in this region. Section 3*c* shows the opening of the Eustachian tube and the pars media plectrum. This appearance of the opening of the Eustachian passage is due to the fact that the middle ear seems to take a slight bend before it opens by the said passage. The ventral end of the annulus tympanicus in *Kaloula* establishes a connexion with the crista parotica by means of a cartilage. This cartilage and also the commissural one between the crista and the pars externa called the pars ascendens are both wanting in *Glyphoglossus*.

The attachment of the pars media plectris with the otic capsule is interesting. In Figure 4*a* the pars media has attached itself to the wall and its maximal attachment is noticed



4a. **4b.** **4c.** **4d.**

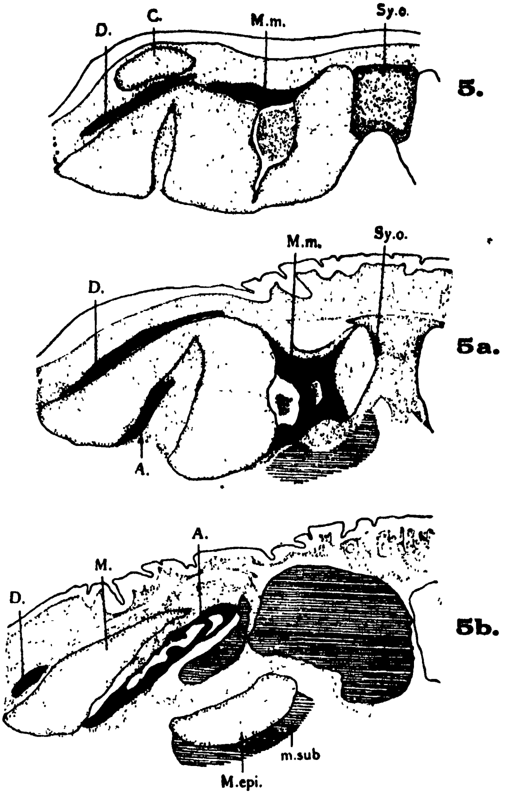
Figs. 4a—4d.

Transverse sections of the ear region of *Glyphoglossus* showing the attachment of the columella.

in Figure 4*b*, where the sheath-like appearance of the columella (pars media) is lost. In Figure 4*c*, the operculum (stapes) makes its appearance and the knob to which the opercular muscle is attached is shown in Figure 4*d*. The conditions enumerated here closely correspond to what has been described for *Phrynomerus* (15) by Villiers.

THE LOWER JAW.

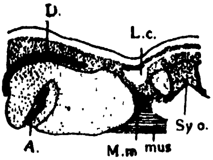
The lower jaw in the South Indian Engystomatidæ and in *Glyphoglossus* conforms to a common plan. At the symphisial region a little ossification (possibly the prerostral) is noticed. The mentomeckelian ossification is very extensive in *Glyphoglossus* (Figures 5, 5*a* & 5*b*) and rather feeble in *Microhyla* (Figures 6 & 6*a*), *Cacopus* (Figure 7) and *Kaloula*. From the mentomeckelian no backwardly directed process can be observed in these forms as described by Villiers for *Phrynomerus* (15) and *Breviceps* (19). No sooner the mentomeckelian bone disappears from the section, a rod-like cartilage other than the one invested by the dentary and the angular is noticed at this region in the sections. To this part of the Meckelian cartilage is attached the submentalis muscle. A reference to the presence of a rod-like cartilage running parallel with the lower jaw has been made by Devanesan (2) and it is now shown definitely that it is a lateral epiphysis of the Meckle's cartilage uniformly occurring in the Engystomatidæ. The dentary is independent of the mentomeckelian bone and establishes no connexion with it. Dorsal to this ossification is seen an unconnected piece of cartilage in *Glyphoglossus* whose exact significance I am not able to determine.



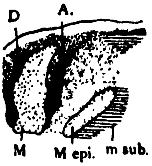
Figs. 5—5b.
Transverse section of the jaw of *Glyphoglossus*.

The muscle submentalis is excessively enlarged and the M. geniohoides is therefore pushed up and the M. hyoglossi assume a lateral position. The exaggerated development of these two former muscles which are believed to be responsible in opening and closing the mouth and narial apertures, is to be closely correlated with the life habits of these narrow-mouthed toads. *Cacopus* at least lives for six months during the year buried under the earth while *Kaloula* and *Microhyla* live in wet earth and very little is known about the habits of *Glyphoglossus*. Mention must also be made along with these terrestrial habits of the Engystomatidæ, the well-developed operculum in *Glyphoglossus*. This is possibly in response to the terrestrial habits as propounded by Varsluys (12).

6.



6a.



Figs. 6—6a.

Transverse section of the lower jaw of *Microhyla*.

In the posterior region of the mouth, Boulenger (1) mentions the presence of a denticulated ridge in *Glyphoglossus* and two in *Cacopus*. The region posterior to the second ridge in *Cacopus* is lamellated and is called the 'pharyngeal organ' by Devanesan (2). The presence of a similar modified tract in the pharyngeal wall is also noticed in *Glyphoglossus*. The histology of the organ is described by Devanesan for *Cacopus* and the same is also true of *Glyphoglossus*. The ciliated mucous epithelium extends over the filiform basement membrane core in the form of long lamellæ. The major part of the lamella is composed of large ovoidal secreting cells while the terminal part is composed of columnar cells with oval nuclei. Devanesan (2) believes that this organ is responsible in secreting a sticky fluid which enables the tongue in capturing the prey. In fact normally, the maxillary glands are attributed with this function of secreting the sticky fluid. He points out that the maxillary glands are absent in *Cacopus* and therefore the function is transferred to the pharyngeal organ. But the sections in the anterior region of the head of *Cacopus* show the presence of large maxillary glands opening into the mouth. Similar glands are also

7.

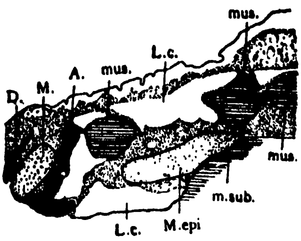


Fig. 7.

Transverse section of the jaw of *Cacopus*.

noticed in *Glyphoglossus*. Therefore what exactly the function of the modified pharyngeal region is, it is difficult to say.

Moreover in *Glyphoglossus* Boulenger (1) mentions the presence of a papilla in the posterior region of the mouth. A section of the papillla is drawn in Figure 2. The histology of the papilla is merely a mass of loose connective tissue covered over by the pharyngeal epithelium.

SUMMARY.

1. A vestigial recess sacciformis is present.

2. The absence of prechoanal sac is noteworthy.

3. The feeble ossification in the sphenethmoid region is recorded.

4. The pars ascendens is absent.

5. The presence of an extraplectral cartilage and a well-developed operculum with a knob are noticed.

6. The "pharyngeal organ" is described. The secretory function of the organ as described by Devanesan is questioned.

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KEY TO THE ABBREVIATIONS USED IN THE TEXT.

A.	..	Angulare (Dermarticulare).
Ant.	..	Antorbital cartilage.
A.t.	..	Annulus tympanicus.
C.	..	Cartilage whose significance is not determined.
c′, c″, c‴.	..	Dorsal, lateral and ventral derivatives of the trabecular cartilage.
Ch.	..	Choana.
D.	..	Dentary.
d. f. v.	..	Ductus fenestra vestibuli.
E.	..	Extraplectral cartilage.
e. olf.	..	Eminentia olfactoria.
E. T.	..	Eustachian tube.
F. P.	..	Frontoparietal.
f. o.	..	Fenestra ovalis.
hy.	..	Anterior cornu of the hyoid.
L. l.	..	Lower lip of the otic capsule.
L. c.	..	Lymph cavity.
M.	..	Meckle’s cartilage.

M. a.	..	Meckle's cartilage and the Angulare.
Max.	..	Maxillary.
Md.	..	Mundwinkeldrüse.
M. e.	..	Middle ear.
M. epi.	..	Meckelian epiphysis.
M. m.	..	Mentomeckelian ossification.
mus.	..	Muscle.
m. sub.	..	Muscle submentalis.
N.	..	Nasal.
op.	..	Operculum.
P.	..	Palatine.
Pa.	..	Paraquadrate.
pap.	..	Papilla.
Par.	..	Parasphenoid.
P. c.	..	Pterygoid cartilage.
pmp.	..	Pars media plectris.
P. Q.	..	Paraquadrate cartilage.
Pt.	..	Pterygoid bone and cartilage.
Qm.	..	Quadrate cartilage and the Quadratomaxillary.
q.	..	Quadrate cartilage.
S. N.	..	Solum Nasi.
Sy. o.	..	Symphisial ossification.
T. c.	..	Transitional cartilage.
V.	..	Vomer.
W. o.	..	Wall of the otic capsule.

POTENTIOMETRIC STUDIES OF COLLOIDAL SOLUTIONS: PART I—STEARIC ACID HYDROSOLS.

BY M. P. VENKATARAMA IYER.

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The interaction between an acid in the colloidal condition and electrolytes has been explained from two rival points of view: (*a*) The 'Chemical Theory' which assumes the reactions to take place in Stoichiometric proportions (Bradfield, *J. Amer. Chem. Soc.*, **45,** 1243, 1923; *J. Phy. Chem.*, **28,** 170, 1924; Usher, *Trans. Far. Soc.*, **21,** 406, 1925–26; Achar and Usher, *J. C. S.*, **129,** 1875, 1927); (*b*) The 'Adsorption Theory' according to which Stoichiometric relationships would be lacking (Mukherjee, *Pres. Address, Ind. Sci. Congress*, 1929; *Ind. Jour. Agri. Science*, **1,** 189, 1931). The variation of the pH of the intermicellary liquid in sols having different concentrations of the acid has been observed by Bradfield to depend upon the dispersion of the particles, since this factor determines the equilibrium condition between the particles and the intermicellary liquid. In order to elucidate the mechanism of the neutralisation process at an interface, the potentiometric titration of a stearic acid sol against strong bases has been studied in the present paper.

EXPERIMENTAL.

Kahlbaum's pure stearic acid, further purified by recrystallisation, was employed for the preparation of the sol. The suspension was prepared by dispersing a dilute methyl alcohol solution of the acid into boiling conductivity water, the alcohol being subsequently removed by boiling. The potentiometric titrations were conducted in Jena glass beakers using hydrogen electrodes of the Hildebrand type against saturated colomel electrode. Tinsley's potentiometer was employed for the measurements. The hydrogen was generated from a kipp and was purified by bubbling through mercuric chloride and potassium permanganate solutions. The alkalis used for the titrations were (1) Carbonate-free sodium hydroxide, (2) Barium hydroxide solution. Bubbling of hydrogen for five minutes was sufficient to secure steady values for the E.M.F.

Stearic acid sols of different degrees of dispersion and concentrations were prepared by varying the experimental conditions. When the ratio of methyl alcohol to water was 2 : 7, sols of the highest concentration were obtained. The factors affecting the formation and stability of these sols have been discussed in a previous paper (M. P. V. Iyer and H. R. Iyengar, *Jour. Mys. University*, **6**, 1, 1932).

In order to find out if any relation exists between the total stearic acid content of the sol and the pH of the intermicellary liquid, sols of different concentrations and different dispersions were prepared and their pH values were measured potentiometrically. It is clear from Table I that it is not the total stearic acid content of the sol, but the size of the particles which determines the " acidity " of the intermicellary liquid.

TABLE I.

Sol No.	Concentration of sol gr./litre.	pH.	Remarks.
A.	0.250	4.32	Consisted of coarse particles. Partially coagulated in a week.
B.	0.624	3.46	Very fine particles. Sol was stable for over a month.
C.	0.665	4.13	The sol was stable for a fortnight.

Tables II *a*, *b*, and *c*, and Tables III *a*, *b*, and *c* give the values obtained in the potentiometric titration of the colloidal acid at three different dilutions when titrated against (1) Sodium hydroxide solution, (2) Barium hydroxide solution. The ' neutralisation ' point and the molar ratio between the alkali and the acid corresponding to the ' neutralisation ' point have been indicated.

TABLE II*a*.

Titration of Sol *vs*. NaOH Solution.

Sol contains 0.624 gr./litre.

Used 0.01 N. NaOH for titration of 40 c.c. of sol.

C. C. of Alkali.	E. M. F. *vs.* Saturated Calomel Electrode at 25°C.	pH.
0.0 c.c.	0.481 volt.	3.46
1.0 ,,	0.528 ,,	4.25
1.5 ,,	0.553 ,,	4.68
2.0 ,,	0.569 ,,	4.95
3.0 ,,	0.595 ,,	5.39
4.0 ,,	0.617 ,,	5.76
5.0 ,,	0.652 ,,	6.36
6.0 ,,	0.732 ,,	7.71
7.0 ,,	0.792 ,,	8.73
8.0 ,,	0.823 ,,	9.26

End point of titration = 5.8 c.c. of .01 N. Alkali.

$$\text{Molecular ratio} \frac{\text{NaOH}}{\text{Stearic Acid.}} = 0.655.$$

TABLE II*b*.

Sol of Table I *twice diluted*.

Used .01 N.NaOH for titration of 40 c.c. of sol.

C. C. of Alkali.	E. M. F. *vs.* Saturated Calomel at 25°C.	pH.
0.0 c.c.	0.491 volt.	3.63
1.0 ,,	0.570 ,,	4.95
2.0 ,,	0.630 ,,	5.99
3.0 ,,	0.718 ,,	7.48
4.0 ,,	0.809 ,,	9.01
4.5 ,,	0.824 ,,	9.26

End point of titration =2.9 c.c. of **Alkali.**
Molecular ratio at end point=0.655.

TABLE IIc.

Sol of Table I *four times diluted.*

Used 0.01 N. NaOH for titration of 40 c.c. of sol.

C.C. of Alkali.	E.M.F. at 25°C.	pH.
0.0 c.c.	0.502 volt.	3.80
1.0 ,,	0.589 ,,	5.27
2.0 ,,	0.778 ,,	8.49
2.5 ,,	0.808 ,,	9.01
3.0 ,,	0.823 ,,	9.26

End point of titration =1.45 c.c. of Alkali.

Molecular ratio $\frac{\text{NaOH}}{\text{Stearic Acid}} = 0.655$.

TABLE IIIa.

Sol ' B ' contained 0.624 gr./litre.

Strength of $Ba(OH)_2$ = .0059N.

C.C. of Alkali.	E.M.F. at 25°C.	pH.
0.0 c.c.	0.484 volt.	3.52
3.0 ,,	0.560 ,,	4.80
5.0 ,,	0.565 ,,	4.88
8.0 ,,	0.571 ,,	4.98
10.0 ,,	0.572 ,,	4.98
12.0 ,,	0.588 ,,	5.27
13.0 ,,	0.705 ,,	7.34
15.0 ,,	0.817 ,,	9.16
16.0 ,,	0.828 ,,	9.33

End point of titration =12.8 c.c. of .0059 N. Alkali.
Molecular ratio at end point = 0.868.

TABLE IIIb.

Sol ' B ' *twice diluted.*

Strength of $Ba(OH)_2$ same as above.

C.C. of Alkali.	E.M.F. at 25°C.	pH.
0.0 c.c.	0.495 volt.	3.70
2.0 ,,	0.567 ,,	4.83
4.0 ,,	0.573 ,,	5.01
6.0 ,,	0.586 ,,	5.24
7.0 ,,	0.616 ,,	5.76
8.0 ,,	0.746 ,,	7.95

End point of titration =7.6 c.c.
Molecular ratio at end point =1.03.

TABLE IIIc.

Sol of Table IIIa *four times diluted.*

Strength of $Ba(OH)_2$ same as Table IIIa.

C.C. of Alkali.	E.M.F. at 25°C.	pH.
0.0 c.c.	0.495 volt.	3.70
1.0 „	0.564 „	4.86
2.0 „	0.574 „	4.98
3.0 „	0.580 „	5.12
4.0 „	0.656 „	6.43
5.0 „	0.744 „	7.92
6.0 „	0.770 „	8.36

End point of titration =4.1 c.c.
Molecular ratio at end point =1.03.

From the titration curves (Figs. I & II), it is to be observed that there is a marked difference in the nature of the curves in

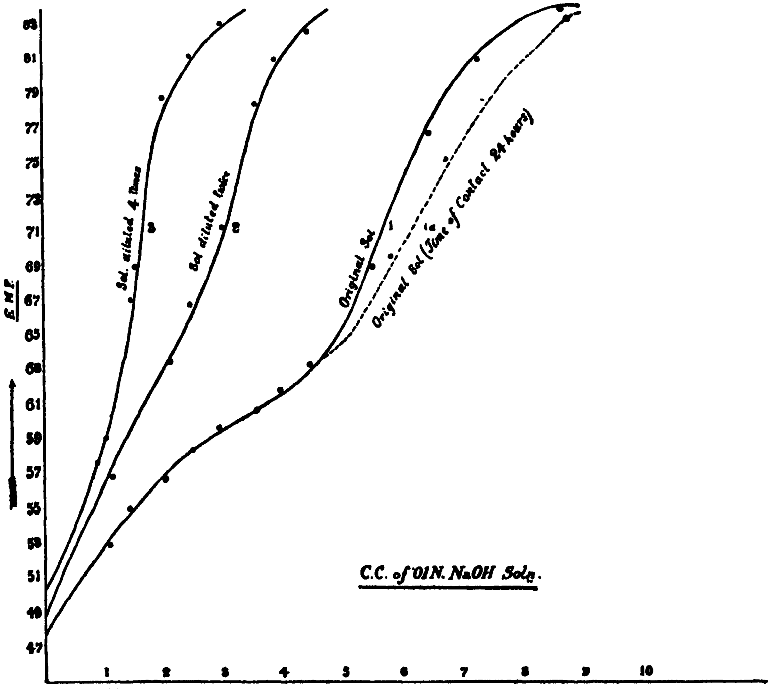

Fig. I.

the case of sodium hydroxide and barium hydroxide. The time of contact of the colloidal acid with the alkali determines the amount of hydroxyl ions taken up. This shows that the neutralisation process at interfaces is not complete directly the alkali is added to the sol. Further experiments were also carried out to investigate the behaviour of finely powdered stearic acid when shaken up with the alkalis in stoppered bottles. It was found that while dilute solutions of sodium hydroxide very slowly react with the acid, barium hydroxide did not enter into any appreciable reaction with the powder. The absence of a definite stoichiometric ratio between the acid in suspension and the alkali required (corresponding to the neutralisation point in the potentiometric titration) is seen from the values obtained. Even after the end point (as indicated by the inflexion in potential) has been reached, the solution remains distinctly colloidal.

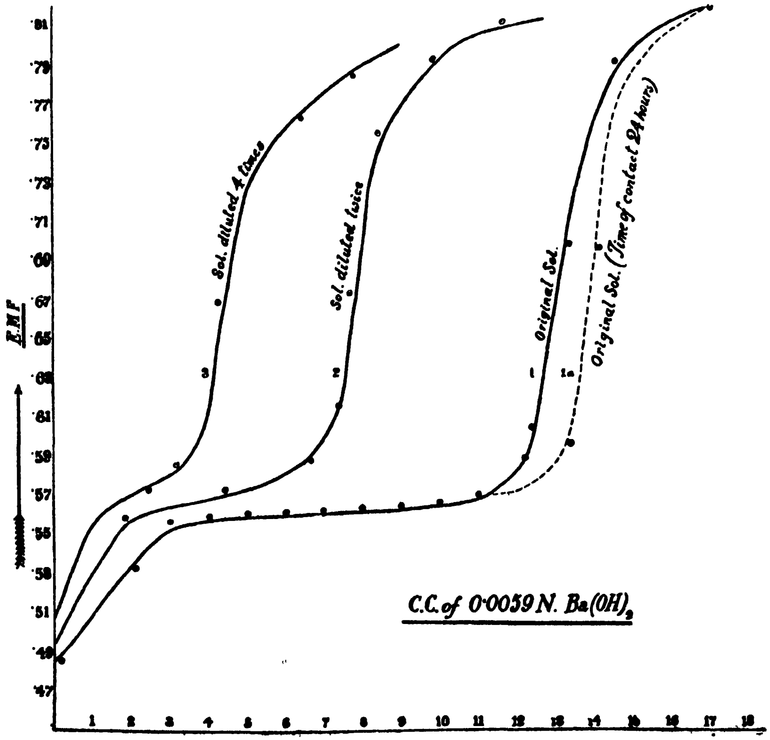

Fig. II.

DISCUSSION OF THE RESULTS.

The process of neutralisation of the colloidal solution by sodium hydroxide may be pictured as follows :—In a stearic acid sol the micelles are negatively charged owing to the adsorption of hydroxyl and stearate ions. The hydrogen ions form the mobile layer. Addition of sodium hydroxide results in the neutralisation of the hydrogen ions of the mobile layer by the hydroxyl ions added. The equilibrium between the solid and the aqueous phase is disturbed, resulting in the desorption of the 'primarily' adsorbed ions. Complications are no doubt introduced (*cf.* McBain, *Colloid Symposium*, 1923) owing to the formation of the insoluble acid soap of sodium ; and this may effectively cover up the surface of the micelles. After the preliminary neutralisation process (which is instantaneous), further reaction takes place if the sodium hydroxide can either (1) penetrate through the adsorption layer or (2) react with the acid soap. Both processes of reaction are slow. This explains why the amount of sodium hydroxide taken up depends upon the time of contact with the sol. The absence of stoichiometric relationship at the point corresponding to the inflexion in potential can be easily understood if one considers the colloidal complex formed during the titration to have the following structure :—

$$\left\{ \underset{\text{Solid phase}}{[X(HA),\ Y(NaA)]} \quad \underset{\substack{\text{Primary}\\ \text{layer}}}{\begin{matrix} A^- \\ OH^- \end{matrix}} \right\} \qquad \underset{\substack{\text{Mobile}\\ \text{layer}}}{H^+}$$

Thus, the stearic acid which forms the 'complex' of the solid phase can react only with extreme slowness with the hydroxyl ions that are added, if the latter can overcome the strong repulsion of the ions in the primary layer.

In the titrations with barium hydroxide the reaction cannot proceed according to the simple chemical equation,

$$2R\ COOH + Ba(OH)_2 \rightarrow (R\ COO)_2\ Ba + 2H_2O$$

since the insoluble barium stearate would effectively cover up the surface. Thus powdered stearic acid enters into very little reaction with barium hydroxide even when the time of contact is several days. On the other hand, the acid in colloidal form reacts with barium hydroxide very easily and the end point is reached when practically the whole of the acid has been neutralised. These facts show that the reaction under consideration is essentially one of neutralisation at the interface. It is known that barium hydroxide does not form an acid soap, and hence there is no possibility for the acid to be present in the solid phase of the colloidal complex at the equivalence point. The reaction between the sol and barium hydroxide may be represented as follows :—

$$2\left\{\underset{\substack{\text{Solid}\\\text{phase}}}{[HA]}\quad\underset{\substack{\text{Primary}\\\text{layer}}}{\begin{matrix}A^-\\OH^-\end{matrix}}\quad\right\}\quad\underset{\substack{\text{Secondary}\\\text{layer}}}{H^+}\quad + Ba^{++} + 2OH^- \rightarrow$$

$$2\left\{\underset{\substack{\text{Solid}\\\text{phase}}}{[HA]}\quad\underset{\substack{\text{Primary}\\\text{layer}}}{\begin{matrix}A^-\\OH^-\end{matrix}}\quad\right\}\quad\underset{\substack{\text{Mobile}\\\text{layer}}}{Ba^{++}}\quad + H_2O.$$

Since the 'deforming' influence of the bivalent barium ions on the anions is sufficiently strong, the barium stearate gets into the colloidal form being stabilised by the hydroxyl ions or by one of its constituent ions. The original structure of the sol being restored enables further neutralisation by barium hydroxide. The steady rise in the pH during the neutralisation of the suspension with sodium hydroxide as contrasted with the nearly constant pH during the neutralisation with barium hydroxide can also be explained on the basis of the above theory. In the first case, the sodium stearate that is formed in solution hydrolyses giving rise to an increase in pH as more and more of it is formed in solution. In the second case, since the barium stearate, being insoluble, is continuously removed, the pH remains steady practically throughout the entire range of the titration.

In conclusion it may be pointed out that the results of the above experiments clearly indicate that reactions between alkalis and an insoluble acid are profoundly modified when the acid is in the colloidal condition : while the 'chemical' theory cannot account for the observed phenomena, the 'adsorption' theory offers a very satisfactory explanation.

SUMMARY.

1. Potentiometric titrations of colloidal stearic acid of different dilutions have been conducted using (*a*) sodium hydroxide, (*b*) Barium hydroxide.

2. The absence of a definite stoichiometric ratio between the alkali and the acid in suspension is pointed out.

3. The results are examined critically with reference to the 'chemical' and 'adsorption' theories, and it is shown that the 'adsorption' theory with suitable modifications involving 'deforming' influence of ions at the interface, can offer a satisfactory solution for the observed phenomena.

The author wishes to thank Prof. B. Sanjiva Rao for his kind and helpful suggestions.

ATMOSPHERIC ELECTRIC POTENTIAL GRADIENT AT BANGALORE (1929).

BY A. VENKATA ROW TELANG, M.A.

(Department of Physics, Central College, Bangalore.)

The Atmospheric Electric Field data for Bangalore for the years 1927 and 1928, with a description of the apparatus and procedure, have already been published.* The recording of the Potential Gradient was continued with the same apparatus at the same place during the year 1929.

Results.—As before, quiet days, *i.e.*, days characterised by the absence of negative potentials and violent oscillations of potential, were selected for obtaining the mean values. The mean hourly values of the potential gradient in volts per metre on the selected days for each month of the year, as well as for the complete year, are given in Table (1). The curves in fig. (1) give the mean diurnal variation of the field for each month of the year and the curve in fig. (2) shows the mean diurnal variation of the field for the year. The results exhibit the same characteristics a sthose of the previous years and do not call for any further remarks.

The curve in fig. (3) gives the monthly mean values of the potential gradient over the year. It is seen to exhibit a maximum in October and a minimum in April. These are seen to be the only maximum and minimum respectively for 1929, unlike 1927 and 1928 which show, each of them two maxima and two minima.

The curve in fig. (2) which gives the mean diurnal variation of the field for the year 1929, has been analysed into harmonic components of periods 24, 12, 8 and 6 hours. A similar analysis of the curve for 1928 has been made for purposes of comparison. Table (2) gives the amplitudes and the phases of the different harmonic components.

The mean values for the two years are in good agreement and the amplitudes and phases of the components in the two years show very close similarity, especially in the case of the higher harmonics.

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* A. V. Telang, "Atmospheric Electric Potential Gradient at Bangalore," *Indian Journal of Physics*, Vol. V, Part VII.

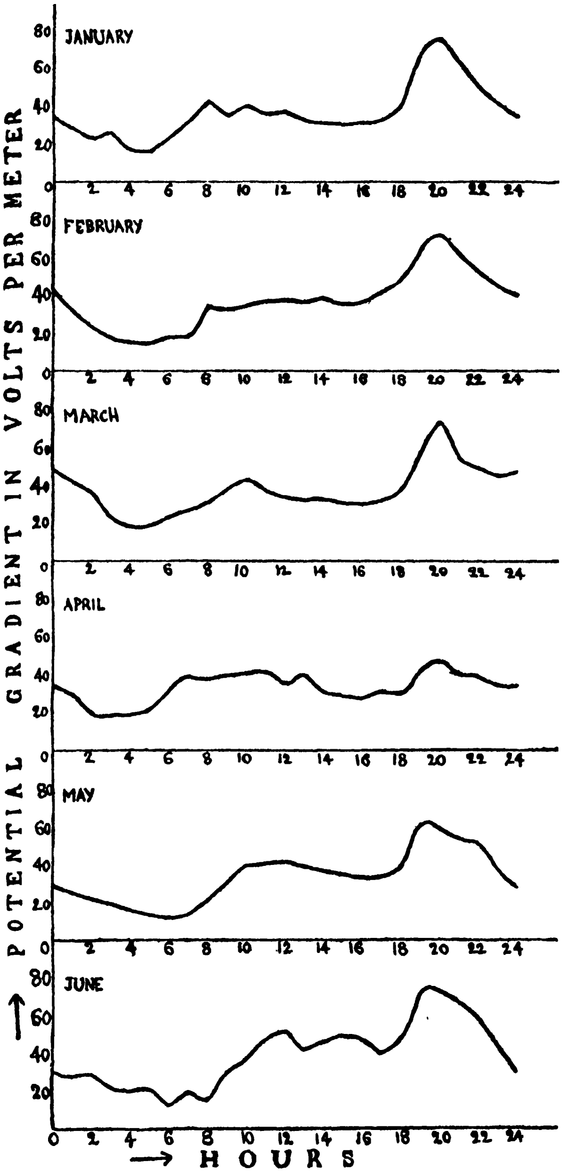

Fig. 1.

Hourly mean values of Potential Gradient on fine days for different months of 1929.

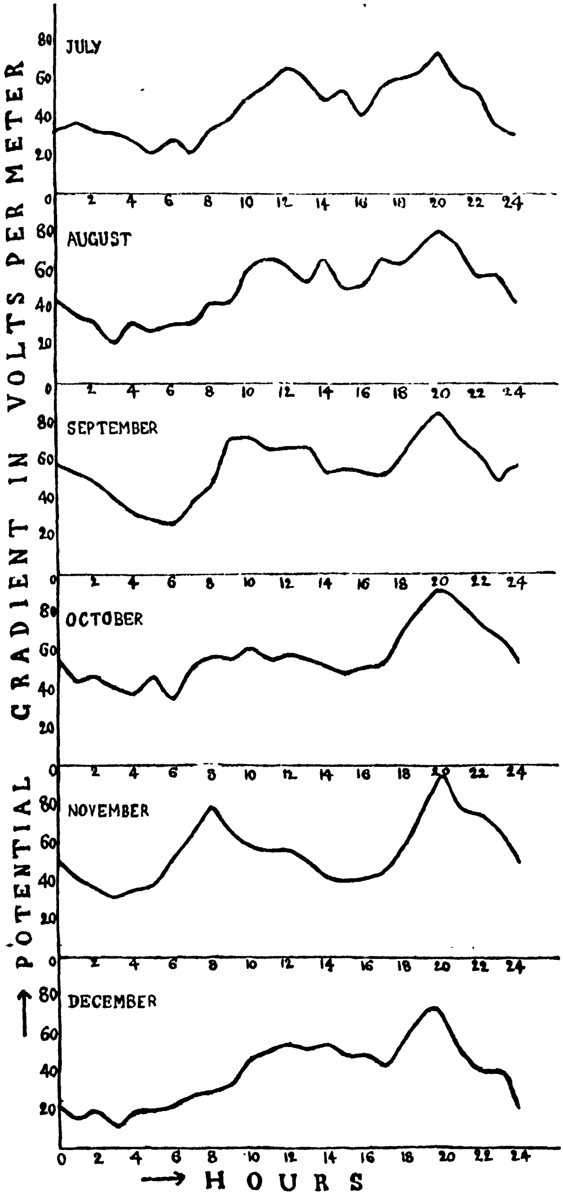

Fig. 1.

Hourly mean values of Potential Gradient on fine days for different months of 1929.

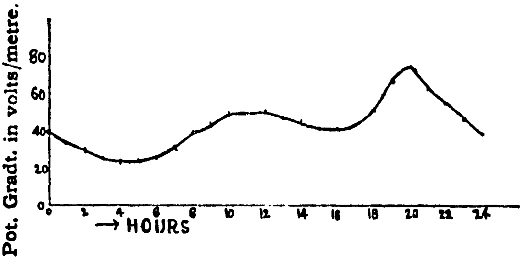

Fig. 2.

Hourly mean values of Potential Gradient on fine days for the whole year 1929.

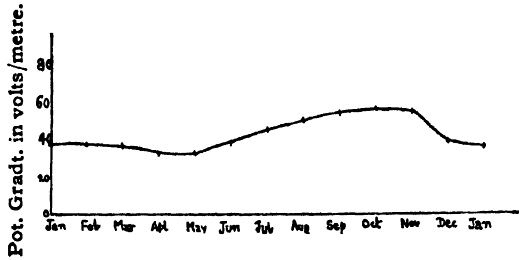

Fig. 3.

Monthly mean values of Potential Gradient.

TABLE (1) 1929.

Monthly mean values of the Potential Gradient in volts per metre at the different hours of the day on fine days only.

Hours of Day.	0	1	2	3	4	5	6	7
January ..	34.7	28.1	24.0	26.4	17.7	17.1	24.6	33.0
February ..	41.4	31.8	23.3	17.0	15.2	14.1	17.1	17.6
March ..	47.2	40.9	35.0	21.7	17.7	18.2	22.3	25.8
April ..	33.6	28.7	18.9	18.0	18.5	20.9	30.9	38.8
May ..	27.9	24.3	21.8	19.3	15.5	12.4	11.6	13.5
June ..	30.0	27.3	28.1	21.0	19.6	20.7	12.5	18.2
July ..	33.0	36.6	32.2	31.6	27.6	21.3	27.9	20.8
August ..	42.9	35.6	30.7	20.8	31.6	27.3	30.9	31.2
September ..	56.9	52.1	47.5	38.4	30.7	27.8	25.8	36.5
October ..	54.9	43.2	45.3	39.7	36.9	46.6	34.7	50.8
November ..	50.4	40.5	36.0	31.1	34.9	37.3	49.9	63.9
December ..	22.0	15.0	19.0	11.0	17.9	18.9	21.8	26.5
Mean ..	39.6	33.7	30.1	24.7	23.7	23.5	25.8	31.4

Hours of Day.	8	9	10	11	12	13	14	15
January ..	42.8	35.7	40.7	36.8	37.7	33.1	31.1	30.4
February ..	35.1	33.6	34.5	37.4	37.9	37.2	39.1	36.0
March ..	30.1	37.4	42.6	36.3	32.5	31.3	32.0	30.0
April ..	37.7	39.5	40.6	41.3	34.0	39.7	29.9	28.0
May ..	20.1	29.3	39.3	40.0	41.2	38.8	37.0	34.4
June ..	15.0	28.7	36.0	46.3	50.5	41.0	44.8	48.0
July ..	34.4	39.5	50.3	57.3	66.0	61.5	49.2	54.4
August ..	41.4	42.0	59.1	64.5	61.3	52.3	64.1	50.4
September ..	45.3	71.0	70.9	64.8	65.6	66.0	53.6	54.7
October ..	55.7	54.1	60.0	54.2	57.2	54.2	51.3	46.9
November ..	79.1	67.0	58.5	55.9	56.7	50.5	42.4	40.3
December ..	28.2	32.7	47.6	52.0	55.6	52.1	55.1	48.2
Mean ..	38.7	42.5	48.3	48.9	49.7	46.5	44.1	41.8

Hours of Day.	16	17	18	19	20	21	22	23	Mean.
January ..	31.6	33.8	41.9	69.8	75.6	62.9	51.6	41.7	37.6
February ..	36.5	42.5	49.2	65.9	72.5	62.3	52.6	45.9	37.3
March ..	29.4	30.6	37.2	58.4	72.1	53.8	48.1	44.6	36.5
April ..	26.6	30.1	29.8	41.3	46.8	39.5	38.0	33.7	32.7
May ..	32.1	33.7	38.4	59.1	58.7	53.6	51.8	34.7	32.8
June ..	46.3	39.4	46.5	70.3	72.4	66.8	57.8	43.7	38.8
July ..	40.6	57.1	61.2	64.2	74.3	59.9	55.6	36.7	45.6
August ..	52.8	66.2	63.8	72.5	80.6	74.0	57.7	58.1	50.5
September ..	53.2	51.8	63.6	76.4	84.1	72.8	63.0	49.6	55.1
October ..	50.1	51.3	69.5	81.6	92.7	85.3	74.2	67.6	56.6
November ..	42.6	45.8	58.6	77.8	95.3	78.2	74.2	67.7	55.6
December ..	49.9	43.5	59.1	72.0	70.4	52.5	42.8	41.6	39.8
Mean ..	41.0	43.8	51.6	67.4	74.6	63.5	55.6	47.1	43.2

TABLE (2).

$$V=a_0+a_1 \sin\frac{2\pi}{24}(h+t_1)+a_2 \sin\frac{2\pi}{12}+\ldots\ldots\ldots$$

where h is the hour after midnight and t the epoch in hours.

	Amplitudes.					Epoch (hours).			
	a_0	a_1	a_2	a_3	a_4	t_1	t_2	t_3	t_4
1928 ..	42.4	-17.2	-8.5	4.9	2.4	0.83	-0.5	-1.8	-0.3
1929 ..	43.2	-13.9	-13.0	4.6	2.5	0.33	-0.25	-1.8	-0.4

REVIEW.

THE ESSENTIALS OF SCHOOL GEOMETRY, WITH ANSWERS.

By A. B. MAYNE (MACMILLAN). 1933. Price 6s.

There has been a considerable amount of improvement that has been effected and is still being effected in the teaching of Elementary Mathematics, in recent years. This new book on the elements of theoretical geometry is intended for the High Schools, and is written so as to embody the principles and recommendations set forth in the Report prepared by the Mathematical Association of Teachers in England.

The book presupposes a course in experimental and practical geometry. The aim of the student has been well kept in view. In their proofs of propositions and of riders, the majority of the older text-books give scanty references to theorems used during the course of the proof, and the student who is not prepared by a careful teacher will be liable to give similar slipshod references in the examination hall. Everyone will agree with the author that so far as the High School student is concerned, " it is better to err, if at all, on the side of prolixity rather than brevity ". " The stress laid in this book upon accurate references to previous theorems will not only help the pupils who use it to avoid a totally unnecessary loss of marks in examinations, but will also result in their learning to express themselves clearly and accurately in all their work."

The treatment of loci is very satisfactory, as contrasted with the lack of rigour to be found in many text-books. Many a book-writer and teacher does not realise that the formal geometrical proof of a locus " always involves the proof of a theorem and its converse".

The definition adopted for the tangent to a circle is not happy. The conception of the tangent as the limiting position of a chord is not difficult. One cannot agree with the author that the average student " gets confused " by the method of limits, after he was able to master the difficult proofs of many of the earlier theorems, for instance, those on congruency.

The present reviewer is not pleased with the inordinately large number of examples given in the book. While every text-book should contain a good number of *illustrative* examples, there must be a limit to this number. Too many examples will kill the enthusiasm of the brighter students, many of whom will have a natural desire of working out through the book from A to Z.

The section on similar figures falls outside the scope of the High School syllabus, at least in India. It could have been brought out separately.

On the whole, the book is welcome, and may be widely prescribed as a text-book.

C. N. S.

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ON THE EQUATIONS OF MOTION OF A NON-HOLONOMIC DYNAMICAL SYSTEM.

By B. S. Madhava Rao, M.Sc.
(Department of Mathematics, College of Engineering, Bangalore.)

The extension of Lagrange's equations to non-holonomic systems in the form of the $n + m$ equations

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_r}\right) - \frac{\partial T}{\partial q_r} = Q_r + \lambda_1 A_{r1} + \dots + \lambda_m A_{rm} \quad (r = 1, 2, \dots n)$$

$$A_{1k}\dot{q}_1 + A_{2k}\dot{q}_2 + \dots + A_{nk}\dot{q}_n + T_k = 0 \quad (k = 1, 2, \dots m)$$

by the introduction of m undetermined multipliers $\lambda_1 \dots \lambda_m$ is very well known.* I propose in this note to derive a form of the Lagrangian equations of motion without the introduction of these parameters and such that the number of equations is equal to the number of degrees of freedom of the dynamical system.

For this purpose, I make use of Appell's form of the general differential equations of a dynamical system whether holonomic or not. These equations, as is well known, are expressed† in the form

$$\frac{\partial S}{\partial \ddot{p}_r} = P_r \quad (r = 1, 2, \dots n-m)$$

where S denotes the function $\frac{1}{2}\Sigma m_k(\ddot{x}_k^2 + \ddot{y}_k^2 + \ddot{z}_k^2)$ and

---

* Whittaker, *Analytical Dynamics* (3rd Edition), p. 215.

† *Ibid.*, pp. 258-59.

$(p_1 \ldots . p_{n-m})$ are co-ordinates equal in number to the degrees of freedom of the system. While Appell's equations are very compact and elegant in form, they are not immediately applicable to practical problems (*e.g.*, the rolling of solid bodies without sliding on arbitrary surfaces) for, the calculation of the function S of the co-ordinates would generally entail a large amount of labour. By a slight modification of the method of derivation of these equations, I have given them the Lagrangian form involving the kinetic energy T as well as the function S. The notation used below is the same as in Whittaker's book referred to above, pp. 258-59 :—

Let the equations of constraint be

$$A_{1k}\, dq_1 + \ldots . + A_{nk}\, dq_n + T_k\, dt = 0 \quad (k = 1, 2, \ldots . m).$$

By the aid of these equations we can express m of the velocities $(\dot{q}_1 \ldots . \dot{q}_n)$ in terms of the others. Taking the co-ordinates corresponding to these last as $p_1 \ldots . p_{n-m}$, let the remaining co-ordinates be denoted by $Q_1 \ldots . Q_m$. With this notation the equations of constraint could be replaced by

$$dQ_i = a_{i1}\, dp_1 + \ldots . + t_i\, dt \quad (i = 1, \ldots . m) \quad \ldots \quad \ldots \quad (1)$$

A virtual displacement in a co-ordinate x_k at time t is given by

$$\delta x_k = \Sigma \frac{\partial x_k}{\partial p_r} \delta p_r + \Sigma_i \frac{\partial x_k}{\partial Q_i} \delta Q_i$$

$$= \Sigma \left(\frac{\partial x_k}{\partial p_r} + \Sigma_i a_{ir} \frac{\partial x_k}{\partial Q_i} \right) \delta p_r$$

which gives the value for the coefficient $\pi_r = \frac{\partial x_k}{\partial p_r}$. To avoid confusion in symbols it is safer to write

$$\pi_r = \frac{\partial x_{ok}}{\partial p_r} + \Sigma_i a_{ir} \frac{\partial x_{ok}}{\partial Q_i}$$

The starting point for the deduction of Appell's equations is the expression

$$\Sigma_k m_k \left(\ddot{x}_k \frac{\partial x_k}{\partial p_r} + \ddot{y}_k \frac{\partial y_k}{\partial p_r} + \ddot{z}_k \frac{\partial z_k}{\partial p_r} \right) = P_r \quad \ldots \quad \ldots \quad (2)$$

In the expression on the left-hand side of this we substitute for $\frac{\partial x_k}{\partial p_r} = \pi_r$ its value obtained above and make similar substitutions for $\frac{\partial y_k}{\partial p_r}$ and $\frac{\partial z_k}{\partial p_r}$. We can therefore consider merely the first term and for simplicity take only a single individual. Thus the expression

$$m_k \left(\ddot{x}_k \frac{\partial x_k}{\partial p_r} \right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

can be written

$$\frac{d}{dt}\left(m_k \dot{x}_k \frac{\partial x_k}{\partial p_r} \right) - m_k \dot{x}_k \frac{d}{dt}\left(\frac{\partial x_k}{\partial p_r} \right) \quad \ldots \quad \ldots \quad (4)$$

$$= m_k \frac{d}{dt} (\dot{x}_k \pi_r) - m_k \dot{x}_k \frac{d\pi_r}{dt} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

but $\dot{x}_k = \sum_{r=1}^{n-m} \pi_r \dot{p}_r + a$

so that $\frac{\partial \dot{x}_k}{\partial \dot{p}_r} = \pi_r$ and hence the first term of (5) could be written as $m_k \frac{d}{dt}\left(\dot{x}_k \frac{\partial \dot{x}_k}{\partial \dot{p}_r} \right)$

Further $\dot{x}_k \frac{d\pi_r}{dt} = \dot{x}_k \frac{d}{dt}\left(\frac{\partial x_{ok}}{\partial p_r} + \sum_i a_{ir} \frac{\partial x_{ok}}{\partial Q_i} \right)$

$$= \dot{x}_k \frac{d}{dt}\left(\frac{\partial x_{ok}}{\partial p_r} \right) + \dot{x}_k \frac{d}{dt}\left(\sum_i a_{ir} \frac{\partial x_{ok}}{\partial Q_i} \right) \quad \ldots \quad (6)$$

The first term of (6) is equal to

$\dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial p_r}$ and the second term

$$\dot{x}_k \frac{d}{dt}\left(\Sigma\, a_{ir} \frac{\partial x_{ok}}{\partial Q_i} \right) = \dot{x}_k \frac{d}{dt}\left(\Sigma \frac{\partial \dot{Q}_i}{\partial \dot{p}_r} \cdot \frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} \right) \quad \ldots \quad \ldots \quad (7)$$

for using (1), $a_{ir} = \frac{\partial \dot{Q}_i}{\partial \dot{p}_r}$ and also

$$\dot{x}_{ok} = \frac{\partial x_{ok}}{\partial t} + \sum_r \frac{\partial x_{ok}}{\partial p_r} \dot{p}_r + \sum_i \frac{\partial x_{ok}}{\partial Q_i} \cdot \dot{Q}_i \quad \ldots \quad \ldots \quad (8)$$

gives $\frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} = \frac{\partial x_{ok}}{\partial Q_i}$.

We can now re-write (7) in the form

$$\frac{d}{dt}\left(\dot{x}_k \Sigma \frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} \cdot \frac{\partial \dot{Q}_i}{\partial \dot{p}_r} \right) - \ddot{x}_k \left(\Sigma \frac{\partial \ddot{x}_{ok}}{\partial \ddot{Q}_i} \cdot \frac{\partial \ddot{Q}_i}{\partial \ddot{p}_r} \right)$$

since from (8) and (1) it follows easily that $\frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} = \frac{\partial \ddot{x}_{ok}}{\partial \ddot{Q}_i}$

and $\frac{\partial \dot{Q}_i}{\partial \dot{p}_r} = \frac{\partial \ddot{Q}_i}{\partial \ddot{p}_r}$.

Expression (6) fully written out is now equal to

$$\dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial p_r} + \frac{d}{dt}\left(\dot{x}_k \sum_i \frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} \cdot \frac{\partial \dot{Q}_i}{\partial \dot{p}_r}\right) - \ddot{x}_k \left(\sum_i \frac{\partial \ddot{x}_{ok}}{\partial \ddot{Q}_i} \cdot \frac{\partial \ddot{Q}_i}{\partial \ddot{p}_r}\right)$$

and hence the original expression (3) is equal to

$$m_k \frac{d}{dt}\left(\dot{x}_k \frac{\partial \dot{x}_k}{\partial \dot{p}_r} - \dot{x}_k \Sigma \frac{\partial \dot{x}_{ok}}{\partial \dot{Q}_i} \cdot \frac{\partial \dot{Q}_i}{\partial \dot{p}_r}\right) - m_k \dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial p_r}$$

$$+ m_k \ddot{x}_k \left(\sum_i \frac{\partial \ddot{x}_{ok}}{\partial \ddot{Q}_i} \cdot \frac{\partial \ddot{Q}_i}{\partial \ddot{p}_r}\right)$$

and the first term of the above could be written as

$$m_k \frac{d}{dt}\left(\dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial \dot{p}_r}\right)$$

Finally, the expression (2) now reduces to the form

$$\frac{d}{dt} \Sigma m_k \left(\dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial \dot{p}_r} + \ldots . + \ldots .\right) - \Sigma m_k \left(\dot{x}_k \frac{\partial \dot{x}_{ok}}{\partial p_r} + \ldots . + \ldots .\right)$$

$$+ \Sigma m_k \left\{\ddot{x}_k \left(\Sigma \frac{\partial \ddot{x}_{ok}}{\partial \ddot{Q}_i} \cdot \frac{\partial \ddot{Q}_i}{\partial \ddot{p}_r}\right) + \ldots . + \ldots .\right\} = \mathrm{P}_r.$$

The first term $= \dfrac{d}{dt}\left\{\dfrac{\partial}{\partial \dot{p}_r}\left[\tfrac{1}{2} m_k (\dot{x}_{ok}^2 + \ldots .)\right]\right. = \dfrac{d}{dt}\left(\dfrac{\partial \mathrm{T}}{\partial \dot{p}_r}\right)$

The second term $= \dfrac{\partial \mathrm{T}}{\partial p_r}$

The third term $= \dfrac{\partial}{\partial \ddot{p}_r}\left[\tfrac{1}{2} m_k (\ddot{x}_k^2 + \ldots .)\right] = \dfrac{\partial \mathrm{S}}{\partial \ddot{p}_r}$

it being understood that, in this case, S is a function only of the $\mathrm{Q}_1 \ldots . \mathrm{Q}_m$, these being, however, determined from (1). With this understanding we can replace S by S′ and finally the equations of motion reduce to the form

$$\frac{d}{dt}\left(\frac{\partial \mathrm{T}}{\partial \dot{p}_r}\right) - \frac{\partial \mathrm{T}}{\partial p_r} + \frac{\partial \mathrm{S}'}{\partial \ddot{p}_r} = \mathrm{P}_r \qquad (r = 1, \ldots . n - m).$$

These equations have the Lagrangian form and it must be noticed that in the expression for T all the n generalised co-ordinates are to be treated as independent.

CHROMOSOMAL ABERRATIONS OCCURRING IN UN-IRRADIATED GRASSHOPPERS.

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The great significance attached to the chromosomal aberrations that result upon the irradiations of plants and animals by X-rays or upon exposure to heat or to radio-active substances, makes it very desirable to collect as much information as possible on the occurrence of such aberrations in non-irradiated individuals. Several authors (Olson and Lewis, 1928; Babcock and Collins, 1929; Hanson and Hays, 1930 and Helwig, 1933) have suggested that the various aberrations occurring in nature have been caused by the presence of radio-active deposits in the soil. In fact, the experimental studies by Helwig have shown the very great similarity which exists between the natural aberrations and those induced by X-rays, and his results are confirmed by this study which is concerned with a batch of material from quite a different region of the Globe. The transmission of these abnormalities from generation to generation could not have been an universal affair, for the Acrididæ have been known to possess very constant chromosome conditions throughout the world. The notable exceptions are the well-known genera, *Stenobothrus*, *Chorthippus*, *Chloeältis*, *Stauroderes*, *Gomphocerus* and a few others which constantly possess multiples of a uniform nature and number. The atelomitic nature of chromosomes in *Trimeotropis* and *Circotettix*, though there is some variation among individuals, has become firmly established in the germinal constitution. The classical instances of multiple formation in *Hesperotettix* and *Mermaria* must have had an origin similar to those in irradiated cells, and in spite of their abundant occurrence, *Hesperotettix* individuals without multiples have not been entirely replaced in nature. The latest addition to our knowledge is the multiple formation in *Sphenarium*, belonging to Pyrgomorphinæ, and in which a multiple has been found to occur in only one of the individuals (McClung, 1930).* In *Drosophila* experimental studies have proved the possibility of transmission of aberrations though in nature individuals possessing them may be inferior to the wild types and thus be eliminated. Sometimes geographical races have been established in plants by the descendants of those possessing them (Blakeslee 1929, and others). The aberrations to be described in the course of this paper, however, are not established features of organisation but only casual ones. The list is not exhaustive for they mostly relate to genera belonging to only one sub-family but they are sufficient to show that the Pyrgomorphinæ retain typical Acridid characteristics though the chromosome number is remarkably different. The author hopes to present at an early date similar studies on a wider batch of material.

The material which is utilised in the present study consists of a large number of specimens of a number of genera of grasshoppers collected and preserved in the usual manner for general chromosome investigations. Most of them were dissected and fixed immediately after collection and in a few cases they had to be reared in the laboratory till they attained a suitable stage. The author's grateful thanks are due to Prof. C. R. Narayan Rao for his advice and encouragement and to the Vice-Chancellor, Dr. E. P. Metcalfe, whose kind interest made it possible for the author to continue his investigations on the chromosomes of grasshoppers.

OBSERVATIONS.

The aberrations observed in un-irradiated individuals of grasshoppers may be classified under two heads, *viz.*, those affecting whole cells and those affecting particular chromosomes. Of the two kinds the former are more frequent and result generally in the formation of giant cells, polyploid cells and degenerating cells. In this group may also be included the visible changes that take place in the physical condition of the cytoplasm resulting in the thinning and attenuation of chromosomes. Among the second kind must be included the formation of multiples, breaking of chromosomes leading to translocation, shifting of fibre attachments and the drawing out of the 'acromites', the formation of constrictions on the spermatogonial chromosomes, etc.

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* Saez has also reported the occurrence of multiples in *Aleuas*, a South American form.

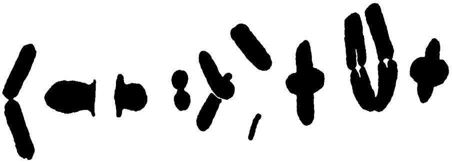
1. *Giant Cells.*—These are very frequently observed. The author recently (1934) described certain interesting kinds of abnormal spermatids in *Aularches* (Pyrgomorphinæ). They were giant forms possessing varying numbers of centrosomes. Those with 2, 4, 8 and a larger number of centrosomes were described and figured. They are not mere degenerating cells as seen from the development of perfectly normal tail fibres from each of the centrosomes. They may be the results of the suppression of cytokinesis without the suppression of the division of the centrosomes. The size of the cells were found to vary directly in proportion with the number of centrosomes present. They are sometimes found to possess inside them large numbers of fragmenting chromosomes of peculiar globular outlines. Similar giant spermatids may be observed in the majority of the species examined.

2. *Polyploid Cells.*—Closely related to the giant cells are the polyploid cells. Most usually they are tetraploids and their features have been studied in broad outline by the present author. They are similar to the 'syndiploid cells' reported by Eisentraut, 1926, and Darlington, 1932. They are found to occur quite frequently but wherever they are present they do not fill up whole cysts, as was described in an abnormal polyploid cyst in the Hemipter *Archemones*, by Wilson (1932). At the most, only a few such cells can be observed in each cyst and they occur in almost all stages of development of the spermatogonia and spermatocytes, especially in *Aularches.* While a detailed account of the behaviour of these cells must be postponed, it is not out of place here to briefly mention the salient features of their organisation. (*a*) They possess a tetraploid set of chromosomes and their volume is correspondingly increased. (*b*) During the spermatogonial stages they do not show any abnormality of behaviour. (*c*) During the first spermatocyte prophases the chromosomes perform typical movements. (*d*) The chromosomes are associated in pairs during synapsis, and not pair to pair,

indicating that the affinity to synapse is between two homologues and not between pairs of them. The zygotene nucleus shows, therefore, 18 typical synapsed loops. This feature is confirmed by two observations; first, the actual counts of the loops themselves which though not quite accurate on account of practical difficulties, due to overlapping, etc., clearly show the tetraploid nature, and secondly, by a study of 'chromomere vesicles'. These have now been established to be characteristic features of nuclei of species possessing them and have also been utilised to demonstrate the constancy of the internal organisation of chromosomes to which they are attached. In the normal cells of *Aularches* two of the peritene loops are found to possess them at constant positions. In tetraploid cells it is revealed that four loops carry them. The behaviour of these vesicles is quite as in normal cells. (*e*) The accessory chromosomes do not pair even though two of them are present in the same cell. They do not also give up their precocious behaviour. (*f*) During the first spermatocyte metaphase the usual kinds of bivalents are formed, only they are diploid instead of haploid (Fig. 8). The two accessories are quite independent of each other. (*g*) In the metaphase of the second division the cells are diploid. This last feature has not been observed in *Aularches*, but in another form *Colemania*. Similar conditions, though not in such detail, are found in the other genera also.

3. *Degenerating Cells*.—These are very commonly found in all the species and need no special description.

4. *Multiple Formation*.—In certain first spermatocyte metaphase of *Aularches* the formation of multiples may be observed. The first spermatocyte metaphase figures of *Aularches* show that there are ten chromosomes of which the accessory one is a rod-shaped structure. Owing to the uniform telomitic nature, the euchromosomes are rings of the *Hippiscus* type or ordinary rods. Two of these rod-shaped chromosomes are united with each other by their proximal ends resulting in the formation of a multiple (Figs. 1 and 2). They are of course extremely rare. In the figures drawn it may be seen that they are so arranged that the free ends are turned towards the same pole, leading ultimately to the equal distribution of the chromatids. The multiple nature of these chromosomes is confirmed by the presence of a small diamond-shaped split at the centre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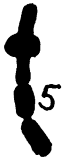
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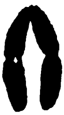
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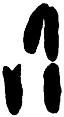
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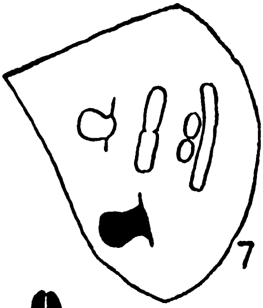
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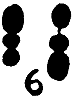
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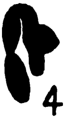
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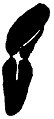
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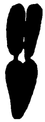
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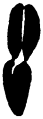
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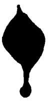
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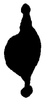
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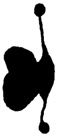
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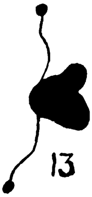
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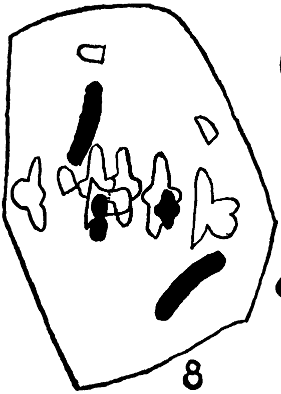
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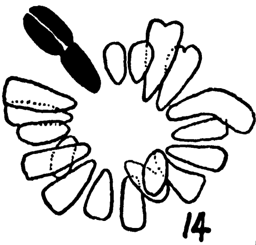
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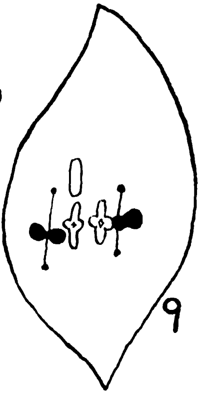
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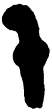
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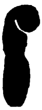
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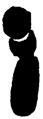
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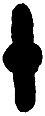
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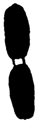
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of each arm. The determination of the exact chromosomes which form this multiple is difficult. But as the studies of metaphase patterns would indicate that the rod-shaped forms are generally smaller in size than those which retain the ring shape for a longer time, it may be reasonably concluded that the multiple forming bivalents are perhaps the fifth and the sixth or the fourth and the fifth counting the smallest chromosome as no. 1.

Another kind of multiple occasionally occurs in *Aularches*. This is also due to the attachment of two chromosomes, one the rod and the other not yet completely drawn into a rod (Fig. 4). These may be the chromosomes six and seven. In one case the free arms of the multiple are directed towards the same pole and the distribution of chromatids is essentially the same as in the above described form. But in another case (Fig. 5) the two bivalents are united and oriented in such a manner that the free ends are directed towards the opposite poles of the nucleus.

In Fig. 3 is drawn another multiple in which one of the chromatids has already separated from its homologue. Other more complicated forms of multiples are not likely to be observed in these grasshoppers, for they possess no atelomitic chromosomes.

5. *Translocations.*—Translocations have not been observed so far in the larger chromosomes but the smallest bivalent in *Aularches* exhibits them in a few cases. In Fig. 6 it may be seen that one of the homologues which generally ought to separate as a single oval-shaped body has become constricted and one of the sections becomes translocated to its homologue, leading to sectional duplication in one dyad and a sectional deficiency in the other.

6. *Shifting of the Fibre Attachment.*—In one of the specimens of *Orthacris* studied all the first spermatocyte metaphases show one of the rod-shaped forms converted into a J-shaped tetrad (Figs. 18, 19 and 20). This occurs with regularity in all the cells. This and another aberration to be described in the spermatogonial complexes are the only aberrations which seem to have persisted for a while and they must have had their origin in the early germ cell stages and have been

handed down through a series of generations of cells. The apparent shifting of the fibre attachment may not be quite actual. The change in the locus of attachment may be due to one of two causes; it may be explained as the result of translocation of a section of another chromosome, or as a consequence of the translocation of a distal section of the same chromosome to the proximal end. The former possibility is vitiated by the fact that no other chromosome has been discovered in the same individual exhibiting a sectional deficiency. The latter possibility is supported by critical observations on length relations of the chromosome itself. It is seen that the length of the section of the atelomitic dyad between the locus of fibre attachment and the point where it is still in connection with its homologue, is generally shorter than that of the normal dyad. In such cases the total length of the dyad including the portion away from the spindle attachment is found to be approximately equal to the length of the normal dyad. Such measurements, if they have any validity, clearly show that the apparent shifting of the spindle attachment is really brought about by the translocation of a section of the same chromosome to the proximal end. In this case there is no sectional duplication or deficiency. Only there must occur some trouble in synapsis due to change of homology.

7. *The Drawing out of the 'Acromite'*.—The 'acromite' is the point of fibre attachment and in normal chromosomes there does not appear to be any constriction at the point though it has been occasionally seen. It is being increasingly recognised that the real unit in karyokinesis is not merely the chromosome but the chromosome along with the spindle fibre which attaches to it. Further Belar's studies (1929) on living cells in hypertonic and isotonic solutions have shown that two forces are necessary for the movements of the chromosomes to the poles. First an autonomous movement of the chromosomes themselves and later the change in the shape of the spindle leading to the drawing up of the chromosomes to the poles. Darlington (1932) believes the movement of the chromosomes at anaphase to be due to 'the gradual waning of repulsion of the poles on the spindle attachments', and describes the anaphase movement to be due to the change of equilibrium.

When the change in equilibrium is abnormal it must lead to aberrations. For example in genetically abnormal plants, such as *Kniphofia*, 'the chromosomes separate but anaphase is never completed....the chromosomes play their part but the spindle fails.' In an unidentified grasshopper belonging to Tryxalinæ (*Epacromia ?*) two of the first spermatocyte chromosomes behave rather peculiarly (Fig. 9). When the anaphase processes commence the short lugs with the spindle attachment are slightly drawn in opposite directions and from this stage onwards the spindle attachments of these bivalents move away in the opposite directions with such rapidity that instead of pulling the whole dyads they carry with them only minute fragments of chromatin which become connected with the main body of the chromosome by thin fibre-like sections. The other chromosomes of the cell are still in the early anaphase stages when the abnormal movement of these chromosomes is taking place. These aberrations are found in all the metaphase cells of the individual.* This abnormal movement of the spindle attachment may be explained on the basis of the above hypotheses as due to either an abnormal repulsion between the attachments or a precocious acceleration of the late anaphase activity of the spindle. This form is being further studied to elucidate the true nature of the movements involved. At present they may be regarded as the effects of the upsetting of the rate of change of equilibrium of the various forces involved. But why exactly they should occur only in two bivalents remains puzzling unless we accept that there are some autonomous repulsive forces in these particular chromosomes themselves which push the terminal attachments wide apart. In the figures 10 to 13 various stages in the movement are drawn.

Occasional instances are found in all species where one of the chromosomes is seen to move away without division to one of the poles in the 1st spermatocyte metaphase. Fig. 7 shows such a cell in *Aularches*. This can only be explained as the total failure of the functioning of the spindle fibres of one side (Fig. 7).

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* Later studies indicate that this peculiar behaviour of these two chromosomes is a constant specific character, similar to the condition in *Hippiscus* (McClung, 1924.)

8. *Constrictions on Spermatogonial Chromosomes.*—There are certain cysts in *Orthacris* which exhibit a peculiar spermatogonial chromosome of some significance (Figs. 14 to 17). Two individuals are found to possess them, though all the cysts do not show them, which indicates that they have arisen quite independently in both the specimens. This chromosome is one of the larger ones and the exact identification is not possible on account of the closely graded series. It generally appears constricted in the middle but on that account does not bend appreciably at the point. It is extended straight and shows its chromatid structure very well. Both the chromatids are constricted and in most cases there is a diamond-shaped slit at the point. This chromosome is so unusual that it is generally very easily distinguished. The origin of this form does not appear to be due to translocation, for the complexes show all the 19 chromosomes (Fig. 14). Perhaps this is the only instance in Acrididæ, in which a spermatogonial chromosome exhibits such a peculiar structure and its significance remains to be decided with certainty.

CONCLUSIONS.

1. There is a great similarity between the aberrations occurring in nature and those induced by X-rays as described by Helwig (1933) in *Circotettix.*

2. Giant spermatids and polyploid cells are frequently observed and are the commonest forms of aberrations.

3. The tetraploid cells occur in all stages of development and exhibit no special features in synapsis, the threads synapsing in pairs as in normal cells. They are very similar in behaviour to the abnormal tetraploid cells studied by Wilson (1932) in a Hemipteran. The metaphase patterns are not in any way different in these abnormal cells.

4. Multiple chromosomes are occasionally formed by the union of two non-homologous rod-shaped bivalents. They may have both their free ends directed towards the same pole, or they may be so attached that they are directed towards the opposite poles.

5. Translocation of a segment occurs frequently in the smallest bivalent, resulting in sectional duplication and deficiency.

6. The shifting of the spindle attachment in *Orthacris* may be due to the translocation of the distal section on to the proximal end of the same chromosome.

7. The peculiar movements of the spindle attachments of two bivalents in an unidentified species may be due to some abnormality in the anaphase processes, most probably to a strong repulsion between the attachments themselves.

8. The spermatogonial metaphases in *Orthacris* sometimes show a most unusually constricted chromosome. Its nature and significance are obscure.

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EXPLANATION OF FIGURES.

1. A first spermatocyte complex of *Aularches* drawn in a row to show the formation of a multiple by two chromosomes being attached by one of their ends. The complex is not arranged in any order. The free ends of the multiple are directed towards the same pole and thus there are three acromites. ×1260.

2. A similar multiple as in Fig. 1. From *Aularches*. ×1260.

3. A similar multiple in which one of the dyads of one of the bivalents is already separated. *Aularches*. ×1260.

4. A similar multiple formed by another combination chromosomes. Free ends directed towards the same pole. *Aularches*. ×1260.

5. A multiple formed by the same elements as in Fig. 4; but they are directed with their free ends towards the opposite poles. There are only two acromites. Corresponding to Helwig's (1929) figure 26. This must result in an unequal distribution of homologues. *Aularches*. ×1260.

6. Single translocation in the smallest bivalent in *Aularches*, leading to unequal distribution. ×1260.

7. A section of the cell of a first spermatocyte anaphase in *Aularches*, to show the non-disjunction of a bivalent due to the failure of spindle attachment on one acromite. All chromosomes are not drawn. ×1260.

8. A section of a tetraploid first spermatocyte anaphase in *Aularches*. All chromosomes are not drawn for they are in different sections. The accessory chromosomes and the smallest bivalents are darkly shaded to show that they are duplicated in a tetraploid cell. The two accessories are seen going to the opposite poles. Normally in *Aularches* only one small pair of chromosomes is present. ×1260.

9. A lateral view of a section of the first spermatocyte metaphase in the unidentified specimen (Tryxalinæ) showing the two peculiar bivalents. ×1260.

10. An early stage in the repulsion of the æromites of the bivalents such as are drawn in Fig. 9. ×2520.

11. Later stage than Fig. 10. ×2520.

12. Later stage than Fig. 11. ×2520.

13. Later stage than Fig. 12. The thin fibre-like section which connects the small granules with the main body may be observed to have lost the tension. ×2520.

14. A spermatogonial metaphase complex of *Orthacris*, in one of the abnormal cysts, showing 19 closely graded series of chromosomes of which one exhibits the unusual constriction in the middle. ×2520.

15, 16, 17. The constricted gonial metaphase chromosome of *Orthacris* separately drawn to clearly show its structure. ×2520.

18, 19, 20. The J-shaped tetrads of *Orthacris*. ×2520.

21, 22. The same bivalents as in Figs. 18, 19 and 20 but as they are found in normal individuals. ×2520.

ASCARIS LUMBRICOIDES IN PERITONEAL CAVITY.

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The specimen described here was handed over to me by Dr. K. Sreenivasachar, Resident Medical Officer, Victoria Hospital, Bangalore, with the following history :—

> "A Hindu girl aged 8 years was admitted to the Victoria Hospital, with a history of distension of abdomen for a week. A diagnosis of general peritonitis was made but no operation was undertaken, as her condition was very low. She died within a few hours after admission. A *post-mortem* examination was done within six hours after death and the following interesting features were noticed. On opening the abdomen, the peritoneal cavity was found to contain hundreds of living as well as dead *Ascaris lumbricoides.* There was a collection of pus in the pelvic cavity and the sigmoid colon was in a gangrenous condition. No obstruction or perforation in the intestine was made out, as the gut was extremely flabby and it tore off easily at the region of the gangrene on attempting to pull out the coils. The abdominal organs, particularly the liver, stomach, spleen, kidneys and coils of intestine, were all adherent to one another. These organs were removed and sent over to the Pathologist."

The mass of organs consisted of the liver, stomach, transverse colon, small intestine and the right kidney. They were all adherent to one another and several *Ascaris lumbricoides* were found projecting out from the various parts. The adhesions were carefully broken up and the relations of the worms to the various organs studied.

The liver was the chief organ to lodge a majority of the *Ascaris lumbricoides.* Four worms were seen buried at the upper and anterior surface of the liver underneath the diaphragm. The adhesion was broken up and the diaphragm was reflected to reveal the position of the worms. Some of them were straight and others coiled up ; and all of them were dead and imbedded in grooved impressions left on the surface of the liver. (Plate 1.)

The posterior aspect of the liver showed a number of worms, about 6 to 8, coiled up into a mass and buried on the surface at the level of the renal impression on the right side. The peritoneum separating the kidney from the surface of the liver was very much thickened due to inflammatory changes. These worms were also dead and had left deep impressions on the surface of the liver. (Plate 2.)

The transverse colon had three worms buried in the *appendices epiploicæ.* Portions of the worms were seen projecting here and there on the outer aspect of the intestine. On dissecting out the *appendices epiploicæ,* which was three times thicker than normal, the worms were found imbedded on the outer wall of the intestine, enclosed in a sheath. They were all dead and had left deep impressions as in other parts. (Plate 3.) The lumen of the intestine was free from marks of perforation and showed no signs of inflammation.

Between the stomach and the spleen a mass of tissue, ¾ to 1 cm. in thickness, was seen and through this was projecting a portion of an *Ascaris lumbricoides.* Further dissection of the part revealed the presence of an entire worm embedded between the spleen and the gastro-splenic ligament. A grooved impression was found both on the thickened ligament as well as the spleen. (Plate 4.)

There were two worms found lying free in the stomach.

HISTOLOGICAL EXAMINATION.

Paraffin as well as frozen sections of the various organs and tissues concerned, were made and examined. The gastrolineal ligament showed considerable thickening as a result of inflammatory cellular infiltration. There were quite a large number of fibroblasts, polymorphos, eosinophyles, plasma cells, lymphocytes and other round cells commonly found in inflammatory changes. Imbedded in the tissue were seen several ova of *Ascaris lumbricoides.* A study of the serial section showed each ovum enclosed in a thick sheath, around which were infiltrations of the inflammatory cells. Foreign body giant cells also were seen here and there, by the side of the eggs. (Plates 5 & 6.) A fresh piece of the ligament was teased out and examined under the microscope. *Ascaris lumbricoides* eggs were seen.

DISCUSSION.

The specimen described above is of interest not only on account of its rarity but also due to the fact that it contributes material to our knowledge of the Pathology of Ascariasis. The matter for discussion in this case is as to the way in which *Ascaris lumbricoides* could have got into the peritoneal cavity ; for the study of the life history of the worms shows they could grow into adult stage only in the lumen of the intestine and nowhere else. Adult dead worms were found on the surface of the various organs buried in the newly formed inflammatory tissue and they must have all passed out of the intestine into the peritoneal cavity when the child was alive.

There are only two ways by which the *Ascaris lumbricoides* could get out of the intestine. One is to pass through a perforation in the intestine and the other by direct penetration from the intestine into the peritoneal cavity.

Some authors are of the opinion that *Ascaris lumbricoides* are " known to penetrate the intestinal wall and escape into the peritoneum, causing peritonitis". There seems to be no case reported in which the worm is seen in the act of penetration. The mouth parts of the *Ascaris lumbricoides* consist of three fleshy lips and they are not adopted for burrowing through tissues. In the case described above, the whole of the lumen of the intestine did not show any evidence of marks of penetration or ulceration. This is a specimen wherein several worms have come out of the intestine but curiously enough, not a single one is seen in the act of penetration. If penetration were a possibility, the specimen on hand ought to have been one to demonstrate the condition. It is therefore highly doubtful, if *Ascaris lumbricoides* are capable of penetrating through the walls of the intestine.

The other possibility of the worms getting into the peritoneal cavity, is through a perforation in the intestine. Kaufman states " sometimes a round worm slips through an intestinal perforation (most frequently of tuberculous ulcers)". Here is a case in which it is not a single worm that has 'slipped through ', but more than a dozen of them without there being any tuberculous ulcer. Stitt, Castallani and Chalmers mention in their books that the worms might pierce the bowel in cases of ulcerative conditions of the bowels. Even the gangrenous portion of the gut did not show any evidence of an ulcer having existed there. I therefore arrive at the conclusion that the worms in this case should have caused intestinal obstruction, and as a sequelæ, there must have been a perforation in the intestine at the sigmoid colon. This perforation in the wall of the intestine, which was unfortunately not traced in the present case, should have existed for a sufficiently long time. The extent of inflammatory reaction resulting in the formation of sheaths and fibrous tissue as described above, indicates the worms to have occupied those places at least two weeks before the death of the child. The perforation at the same time should have been big enough to allow several of the worms to pass through. It is interesting, however, to note that the child has survived for such a long time with a sufficiently big perforation without much distress.

My thanks are due to Dr. K. S. Achar for placing the specimen at my hands and to Mr. L. N. Rao of the Central College for preparing the photomicrographs.

SUMMARY.

1. *Ascaris lumbricoides* were found in the peritoneal cavity of a child; some of them were dead and buried on the surface of liver, intestine and spleen and others were living and free in peritoneal cavity.

2. Intestinal perforation was not actually seen at the *post-mortem* examination.

3. The possibilities of the ways in which the worms could have got into the peritoneal cavity have been discussed.

LITERATURE.

1. Manson's *Tropical Diseases*, 9th Edition, page 587.
2. *Tropical Diseases*, Stitt, 5th Edition, page 520.
3. *Manual of Tropical Medicine*, Castallani and Chalmers.
4. *Text-Book of Zoology*, Parker and Haswell.
5. *Pathology for Students and Practitioners*, Kaufman. Trans. by S. P. Reimann, Vol. II, page 853.

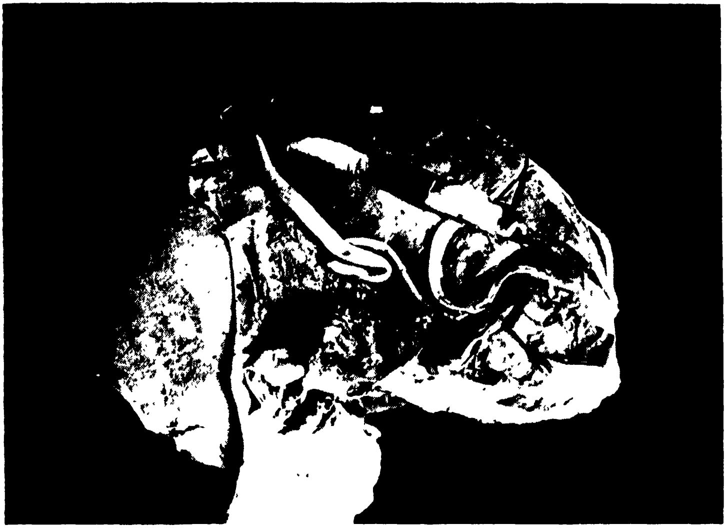

Plate 1.

Ascaris lumbricoides at the upper and anterior aspects of the liver.

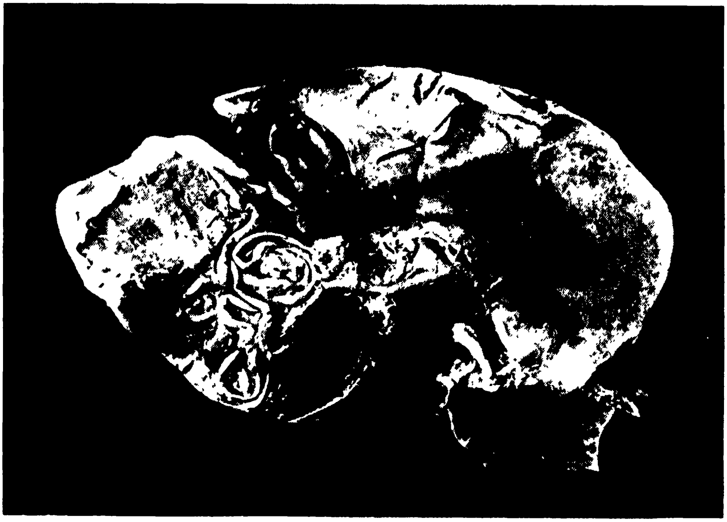

Plate 2.

Ascaris lumbricoides at the posterior aspect of the liver.

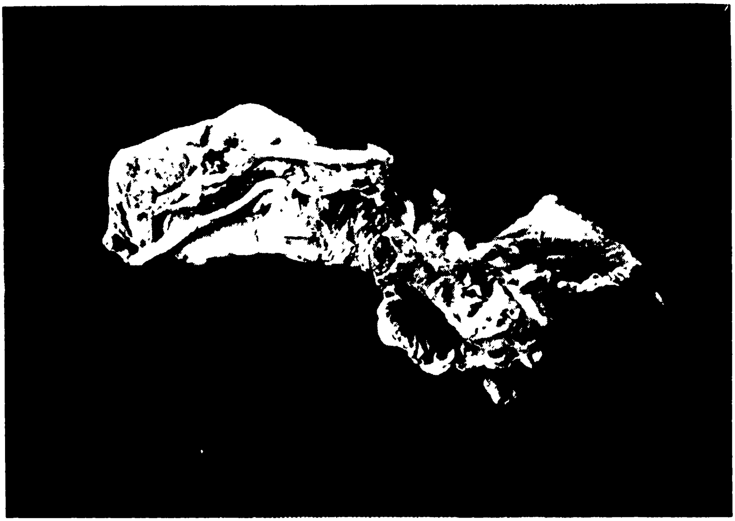

Plate 3.

Transverse colon with *Ascaris lumbricoides*.

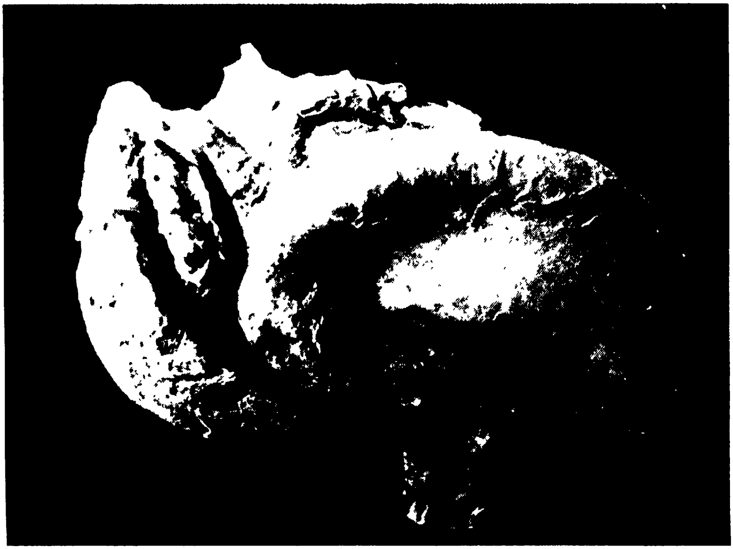

Plate 4.

Ascaris lumbricoides between the spleen and gastro-splenic ligament.

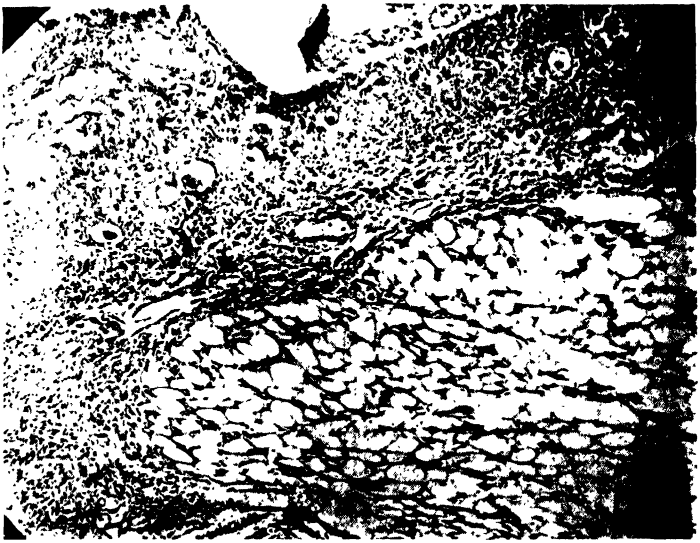

Plate 5.

Section of gastro-splenic ligament showing eggs of *Ascaris lumbricoides*
(Low power. [illegible])

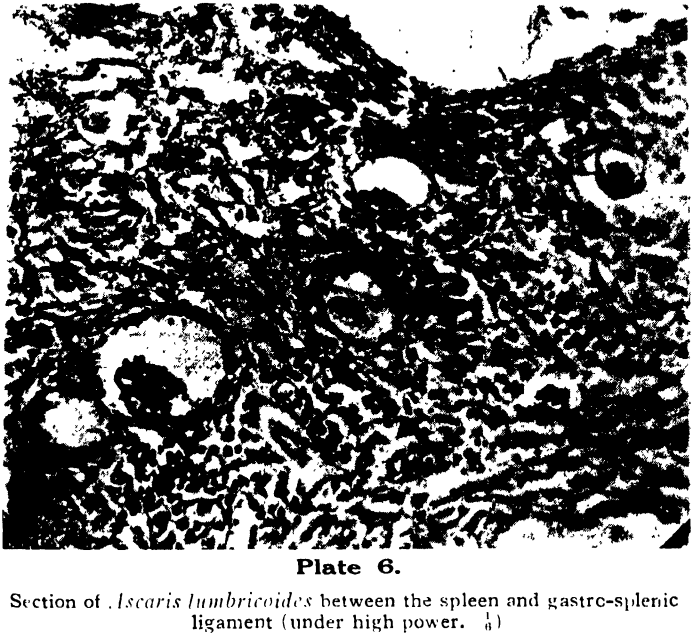

Plate 6.

Section of *Ascaris lumbricoides* between the spleen and gastro-splenic ligament (under high power. $\frac{1}{8}$)

TIPU'S MILITARY EXPENDITURE.

(An Attempted Estimate.)

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The military expenditure in the days of Tipu and his father was probably the most important item of expenditure. Although sufficient data are not available to determine it with certainty, yet it appears possible to get some idea of the probable cost. The strength and organization of the army therefore will be determined before a calculation of the expenses is attempted.

According to a European deserter from the Mysore Army in 1783[1] Tipu's troops besieging Bidnore numbered "sixty thousand horses; thirty thousand regular well-disciplined sepoys; six hundred French European infantry under the command of Colonel Cossigny; Monsieur Lally's troops composed of Europeans and natives, and a French troop of European dismounted cavalry, under the command of Monsieur Boodena, a captain in the French service; with their hundred pieces of artillery from four to twenty-four pounders; and irregulars. The whole supposed to exceed one hundred and forty thousand fighting men." John Campbell, the British officer at Mangalore, who records the foregoing statement, remarks,[2] "this proved to be a very just account of the enemy's strength", when Mangalore was besieged some time later. These figures are corroborated by what is said to have existed in 1781 in the last days of Hyder.[3]

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[1] Campbell's *Defence of Mangalore* (1781), p. 6.

[2] *Ibid.*, also *Home Miscellaneous*, Vol. 218, p. 44.

The *Home Miscellaneous* series of *MSS.* to be found in the India Office Records Department consists of miscellaneous letters, reports, diaries, etc., in MS., copies as well as originals, sent to the Home authorities from India. The *MSS.* cover almost the whole period of the Company's life in India. The hundreds of volumes of this series are a veritable mine of information. I am grateful to the India Office for permitting me to make use of this series among others.

About this time in 1783, Tipu made his first attempt at the reorganization of the army.[4] The infantry was divided into various brigades called *kushūns* each under a *sipāhdar* corresponding to the brigadier-general. With the help of a *bukshi* and two *mutsaddies*, he was responsible for the accounts and civil administration of the brigade, in addition to himself being in charge of its military affairs. To help him on the administrative side there were also a *saryusakchi* or brigade-major and the *yusakchis* or adjutants who conveyed the *sipāhdar's* reports to the Sultan. Each *kushūn* was composed of four *risālas*[5] of infantry and, according to Tipu's officer, had one *tīp* of cavalry attached to it.

Each *risāla* or regiment was placed under the charge of a *risāldar* and was divided into four *jowks*[6] or companies each under a *jowkdar*, corresponding to *subedar* of the Indian army. The *jowk* consisted of about 90 men[7] divided into 15 *yuzuks*.

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[3] Eyre Coote to President at Fort St. George, 6th July, 1781. (Forrest: *Selections, Maratha Series*, Vol. III, p. 792.)

[4] This account is based on the *Futhul Mujahideen*, extracts from which are given in Kirkpatrick's *Select Letters of Tipu Sultan*, appendix (i); and on the account of one of Tipu's officers given in 1790. *Home Miscellaneous*, Vol. 251, pp. 300 and ff. This account is "taken from the information of Mahomed Khoushro who left Tipu near Dindigul in May, 1788", and is dated Madras, 1st December.

Lord Macartney in his letter to the Secret Committee of the Court of Directors dated 30th January, 1785, refers to this reorganization. Paras 12 and ff. *Home Miscellaneous*, Vol. 247, pp. 378 and ff.

Munro in a letter to his father dated 17th January, 1790, refers to Tipu's scheme of reorganization. (Gleig, *Life of Sir Thomas Munro*, Vol. 1, p. 85.)

[5] Tipu's letters dated 5th and 9th May, 1785 (Kirkpatrick, *op. cit.*, pp. 57 and 298, Nos. XLII and CCLXX) indicate the *risāla* to be a part of a *kushūn*. The strength of a *risāla* varied from 500 to 1000. *Ibid.*, pp. 59-60.

[6] Tipu to Burhanuddeen, 5th May, 1785 (Kirkpatrick, *op. cit.*, p. 56, No. XLI) indicates *jowk* as a subdivision of a *risāla*.

[7] According to the account of Tipu's officer the *jowk* consisted of 125 men. (*Home Miscellaneous*, Vol. 251, p. 301.)

The officer next below in rank to the *jowkdar* was the *sarkhil*, the *jamedar* of modern days, with another officer the *jamedar* equal to the *havildar* of to-day. Each *yuzuk* consisting of six rank and file called *jish* was commanded by the *yuzukdar*.

The smallest unit of the cavalry was the *yuz* under a *yuzdar* and composed of 95 troopers or *uskars*. The *sarkhil* was the next higher officer. The *tīpdar* commanded a *tīp* made up of four *yuz*; four *tīps* made one *moukoub* under a *moukoubdar*.

It is not known if the 10,000 troops from Mauritius referred to in Tipu's letter to M. Moneron[8] arrived at all in India in 1786-87, or at any other time. However, in 1789 when the Sultan invaded Travancore, the army with him is said to have been 35,000.[9] That this figure did not probably indicate the whole of the Mysore army is corroborated by a statement of J. Chamiers, a contemporary.[10] According to a Portuguese deserter from Mysore, the troops stationed in Malabar alone numbered 16 *kushuns* and 4 *risālas* with 3,000 or 4,000 cavalry and numerous guns, making in all 34,000 regular foot and 3,000 or 4,000 horse. If there were in a single province nearly 38,000 troops stationed, the total military strength of Mysore must have been considerable. In fact a letter from John Hollond dated 5th August 1789,[11] gives the number of troops stationed in various parts of the country at 60,000 regular infantry; "there are besides at Coimbatore 30,000 matchlock men and irregulars, and more are expected." In this estimate there is no mention of either the cavalry or the commissariat, or even of some of the garrisons as in Chittaledoorg, and Gurumconda. On the other hand it perhaps incorrectly takes the strength of a *kushūn* to be 4,000, while various accounts including the Sultan's own military regulations of 1793-95 give the figure at not more than 3,000.[12]

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[8] Letter No. CCCXCIX, dated 19th November, 1786. (Kirkpatrick, *op. cit.*, p. 416.)

[9] Wilks, *History of Mysore*, Vol. II, p. 140.

[10] *Home Miscellaneous*, Vol. 248, p. 425. This account contains detailed statements of the number of *kushūns* with the names of the *fouzdars* and *subedars*, stationed in various parts of Malabar. Some of the particulars about the cantonments and the number of troops are corroborated by a letter from John Hollond to Lord Cornwallis of the 5th August, 1789. (*Idem.*, p. 405.)

[11] John Hollond, Fort St. George, to Lord Cornwallis, 5th August, 1789. (*Home Miscellaneous*, Vol. 248, p. 405.) See also Powney to the Governor in Council, Fort St. George, 23rd July, 1789. (*Idem.*, p. 435.)

As against these figures can be put forward the statement of one of Tipu's *mutsaddies* or accountants taken prisoner by the British troops. According to him[13] the Mysore army consisted of 12,000 irregulars armed with *jukes* and matchlock and 6,000 cavalry. These figures do not appear to denote the strength of the whole army. If they do, their trustworthiness is doubtful. For the other accounts of the Mysore army uniformly give higher figures. Moreover, it is natural to expect a Mysore accountant to refrain from giving the true strength of his master. On the contrary, Hollond's account seems more trustworthy because it is more detailed and gives the number *kushūns* mentioned in various places. Further it is given by a renegade from the Mysore army who had long served under the Cochin Durbar, who left the Mysore service once for all and who could therefore have no interest either in minimising or in exaggerating the strength of Tipu. Above all, the higher figures are corroborated by other sources.

Thus an officer of Tipu writing in 1790[14] gives the strength as follows :—

Cavalry :

Stable horse	7,000
Hired horse[15]	12,000
	19,000

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[12] Kirkpatrick, *op. cit.*, appendix pp. xcvii and xcix : The Sultan's regulations of 1793 gave the strength at 1392 (*Ibid.*, p. xcvi) while according to *Futhul Mujahideen*, it was 2928.

[13] Powney to the Governor-General, 4th January, 1790. (*Home Miscellaneous*, Vol. 248, p. 435.)

[14] *Home Miscellaneous*, Vol. 258, pp. 300-303. This account is "taken from the information of Mahomed Khoushro who left Tipu near Dindigul in May, 1788."

[15] Of these the officer says that "there are not above 3,000 of the hired horse that can be called good cavalry—the rest are more of the plundering kind." This suggests that 3,000 were *silladar* horse and 9,000 predatory.

Artillery :	
Golandazies (gunners)	2,000
Lascars	8,000
European artillery two companies	30
Regular Infantry :	
Chelas and *Ahmedies*	6,000
Dismounted troopers	8,000
Sepoys	55,000
Irregular Infantry :	
Fighting *peons*	40,000
Rocketmen	5,000
	45,000
Pioneers, labourers, etc.	70,000
Two *risālas* of *topasses* with 100 Europeans	900
Lally's Party	630

It will be observed that, according to John Hollond, the regular foot numbered 60,000 and the irregulars, mobilised at Coimbatore, 30,000, as against 69,000 and 45,000 given by Tipu's officer. Further, according to a memorandum of December 1793[16] at the beginning of the war of 1790 " Tipu's force was estimated at 45,000 regular infantry and about 20,000 horse exclusive of irregular *peons* which are called *kundachar*." Moreover, Sir Thomas Munro writes in 1790[17] that " Tipu supports an army of 110,000 men, a large body of which is composed of slaves, called *Chaillies*." A British officer records in April 1791 that the Mysore army encamped near Bangalore alone was " at least 80,000 men". Again, the number of casualties on the Mysore side in the war of 1790-92 is alleged to have been 49,340. Under these circumstances the figures given by Tipu's officer may perhaps be assumed as correct.

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[16] Memorandum of Tipu's military force, etc., Dec., 1793. (*British Museum Additional MSS.*, Vol. 13659, folios 79-85.) The *British Museum Additional MSS.* comprise documents (originals and copies) in English and other languages relating to various topics and countries and presented to the British Museum.

[17] Letter to his father dated 17th Jan., 1780. (Gleig, *op. cit.* Vol. 1, p. 85.)

It has been truly said of Tipu that "his father Hyder was partial to his cavalry and kept a much larger body than he does; he is partial to his infantry and has made great augmentations to them."[18] To compare :—

	Hyder (1780)	Tipu (1790)
Cavalry (excluding predatory horse).	32,000	16,000
Infantry	27,000	69,000
Peons (fighting only)	28,000	40,000
Rocketmen	7,000	5,000

These figures indicate that while Hyder placed his trust mainly in the cavalry and the artillery, his son depended upon the infantry. It may be said that Tipu halved the numbers of the former and doubled those of the latter. These changes had both military and financial consequences. Tipu, as Sir Thomas Munro observes,[19] weakened himself by this reform. Financially there was some economy as the cavalry was paid higher than the foot. The financial effects will be discussed presently.

In March 1793 the Sultan addressed an ordinance to the Military Department (*Mir Miran*) detailing a new scheme of organization.[20] In August of the same year the sovereign himself drew up a memorandum differing very little from the ordinance, except that in August there was some reduction in the cavalry.[21] This reorganization was very probably the outcome of the recent defeat of the Mysore troops in the war of 1792, and of the monarch's desire to organize an invincible army for the next war against the Company.

The army was divided into two parts, the infantry and the artillery on the one side, and the cavalry on the other. The infantry itself comprised the regular troops and the *peons* or the irregulars. The former were systematically drilled and disciplined and fully and regularly paid. This regular infantry was divided into five *kacheris* and composed of 27 ***kushūns***, the first two *kacheris* having six *kushūns* each and the other three only five each. Every *kushūn* was placed under a *sipāhdar* and had two field pieces attached to it. It consisted of four *tīps* each commanded by a *tīpdar*. The *tīp* was divided into four *yuz* under four *yuzdars*. The strength of one *yuz* was 87 men, that of a *tīp* 348 and of a *kushūn* 1,392.[22] The *kushūn*, however, had attached to it one *jowk* of rocketmen (39 men), two *jowks* of matchlockmen (112 men), two *jowks* of *khulasies* or lascars (122 men) and drivers, etc., in all 360 men. In addition each *tīp* had its own staff just as each *kushūn* had. The total number of men in each *kushūn* was thus 1,752 and in the regular infantry (27 *kushūns*) 47,304.

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[18] *Home Miscellaneous*, Vol. 251, p. 302.

[19] Munro to General Wellesley, 16th Dec., 1803. (Gleig, *op. cit.*, p. 181.)

[20] Kirkpatrick, *op. cit.*, appendix L.

[21] *Ibid.*, p. xcii.

In addition to this there appear to have been 1,000 troops (including 500 Europeans); the old corps of M. Vigie, three independent *tīps* of regular infantry attached to the first three *kacheris*, gun-lascars, drivers, pioneers, etc., bring the total of the regular foot to 52,760. But in actual fact this does not appear to have been the number. As the Memorandum observes[23], " although 1,296 non-commissioned officers and privates be the established strength of a *cushoon* of 4 *risālas*, some *cushoons* are above the complement and the majority are under it," and, moreover, the number of *kushūns actually* existing seems to have been only 22,[24] and may be reckoned on an average at 1,000[25] men. To this must be added the independent *risālas* comprising mainly of *chelas*, numbering about 8,000,[26] and the gunners at 2,000.[27] Thus the regular foot actually in existence would be about 32,000, as against 52,000 according to the regulations.

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[22] A slightly different account is found in the Memorandum of 1793. The number of N. C. O.'s and privates in a *kushūn* is given as 1,296, each *jowk* having 84 fighting men and officers. But the differences are too insignificant to be considered.

[23] Memorandum of December, 1793. (*Bri. Mus. Add. MSS.*, Vol. 13659, folio 83.)

[24] *Idem.*, folio 80.

[25] *Ibid.*

[26] *Ibid.*

[27] *Bri. Mus. Add. MSS.*, Vol. 13659, folio 84.

The other branch of infantry consisted of the *peons* or irregulars who appeared to have served as garrison troops. Their number is mentioned in Tipu's ordinance of 1793, as 25,000,[28] 15,000 of whom were in the provinces and 10,000 in the capital. These troops were very probably reduced after 1792 in view of the reduction of the kingdom to nearly half its former extent, and in view of the demolition of some forts in the kingdom,[29] which naturally decreased the number of places to be garrisoned.

The cavalry was of three kinds. The regular cavalry or *sowar uskar* consisted of men whose horses were owned by the State and maintained at its expense.[30] It was divided into three *kacheris* or divisions, each consisting of six *moukoubs* or regiments of 389 horses and 376 men. A *moukoub* was divided into four *tips*, each *tip* into two *yuz* and each *yuz* into two stables, generally consisting of 22 horses each. Each division had guns and gunners attached to it. Thus the total strength of the regular horse would be about 67,000 men and 7,000 horses ; and a little more than the regulated strength appears to have actually been in existence.[31]

The irregular horse consisted of the *silladars* and the predatory horse, called *kuzzuk*.[32] The organization of this branch of the army is uncertain. For according to Tipu's Regulations[33] the *silladars* were divided into two *kacheris* each commanded by two *bukshies* and divided into 8 *risālas* of 250 horses each, besides the usual staff of *mutsaddies*, surgeons, etc. The total number of the *silladars* would be 4,000.[34] The predatory horse is said to have been composed of 3 divisions of 2,666 each divided into 6 *risālas* of 260 each officered in the same manner as the *silladars*. The total number of the predatory force is stated at 8,000.

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[28] Kirkpatrick, *op. cit.*, appendix p. cii. According to the Memorandum of December 1793 (*Bri. Mus. Add. MSS.*, Vol. 13659, folio 79), "their number cannot easily be ascertained, but it is said there are 1,000 peons in Tipu's pay for every lac of pagodas of revenue which being estimated at 36 lakhs, it may be supposed there are 36,000 peons of this description." Under these circumstances Tipu's figures being more definite and smaller may perhaps be referred.

[29] Bangalore and Hosur, for instance, were destroyed after the war by Tipu's own orders. (Malcolm's Abstract, Martin's *Despatches of Wellesley*, Vol. 1, p. 655.)

Also see Colin Mackenzie's *Journal of Observations* on the march from Hyderabad to Seringapatam in 1798-99. (*Bri. Mus. Add. MSS.*, Vol. 13633, folio 33.)

[30] Memorandum of December 1793. (*Op. cit.*, folio 80.)

[31] The number is given at 7,000 in the Memorandum of Dec. 1793. (*Op. cit.*, folio 84.)

[32] Kirkpatrick, *op. cit.*, p. ciii.

[33] *Ibid.*

On the other hand it is said[35] that "the irregular horse are not formed into corps and each officer commanding a party makes such arrangements as he thinks proper," and that the two kinds of the irregular cavalry differed from each other in that the commanding officer of one contracted to furnish both man and horse for a higher pay than in the other where the horses were owned by the State. The total number of both kinds of irregular horse is given as 6,000.

Here again it is probable that although according to Tipu's regulations the irregular horse were expected to be 12,000 in all, actually just after the war there were only 6,000; for the war of 1790-92 coupled with the great inclemency of weather in those years is said to have very greatly reduced his cavalry.[36]

According to the above-mentioned computations the Mysore forces in 1793 numbered as follows:—

Infantry :	
Regulars[37]	32,000
Irregulars	25,000
Cavalry :	
Regulars (stable horse)	7,000
Irregulars	6,000
Total strength ..	70,000

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[34] It is not clear how on these facts Kirkpatrick gives the number as 6,000. (*Ibid.*)

[35] Memorandum of December 1793. (*Op. cit.*, folio 84.)

[36] Extract from a letter from camp between Hosur and Raicotta dated 10th August, 1791. (*Home Miscellaneous*, folio 84.)

[37] These include 2,000 gunners.

In this connection what appears to be a mistake about the Sultan calls for some remarks. It is generally held[38] that after 1792 in spite of the advice of his officers and in the face of the decaying finances Tipu refused to diminish his army. "After the peace of 1792," says Beatson,[39] "some of his counsellors strongly urged him to discharge the superfluous persons attached to the different departments of his government, and to diminish the extent of his military establishment; without which his receipts would never be made adequate to his expenses. He replied, 'these people are fed by God, not by me,' and he never would listen to suggestions for reducing any part of his establishments."

This opinion does not appear to be borne out by the preceding discussion, and seems to do injustice to the Sultan. On the other hand, Tipu appears to have diminished his forces to a considerable extent, although perhaps not in proportion to the decrease in his prosperity. Thus the forces were :—

	1790.	1793.
Infantry :		
Regulars	69,000	32,000
Irregulars	45,000	25,000
Artillery	10,000	....
Cavalry :		
Regulars	7,000	7,000
Irregulars	12,000	6,000
Total ..	143,000	70,000

Even according to the military regulations the total strength should still have been 91,000.

A word of explanation is needed here. The pioneers numbering 70,000 mentioned as existing in 1790 are not counted above on the assumption that they existed in 1793 also. But it is probable that there was a proportionate reduction in this branch of the army, for if any troops were important to Tipu it was certainly not the pioneers, and if there was to be any sacrifice, the fighting Sultan would naturally lay his hands on this evidently less useful unit of the army.

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[38] Wilks, *op. cit.*, Vol. II, p. 288. Beatson's *War with Tipu Sultan*, p. 153.

Stuart's *Catalogue of the Library of Tipu Sultan*, Introduction p. 70

[39] *Op. cit.*, p. 153.

Even assuming that the pioneers continued untouched the figures given above show that one of the effects of the war of 1792 was the reduction in the forces by nearly half.

Little information is available until 1798. However, in the treaty Tipu proposed " to the people of the Isle of France and Le Re-Union,"[40] on 2nd April 1797, Tipu writes, "As soon as the French army shall have embarked, I engage to march with my troops, which shall, *in the first instance*, consist of 30,000 cavalry and 30,000 infantry and artillery, well disciplined in arms, ammunition and everything necessary for the success of our enterprises." It is not clear what the phrase ' in the first instance ' signifies and whether the army mentioned was actually existing or whether the numbers indicate the troops which Tipu expected to recruit.

Between 1793 and 1798 the Sultan appears to have effected some more changes in the organization of the army, resulting in a decrease of its numbers and a reduction in expenditure.[41] The regular infantry in June 1798 consisted of seven *kacheris* instead of five and the total number of ***kushūns*** was 28 instead of 27, each *kacheri* uniformly consisted of four ***kushūns***; but the strength of a *kushūn* was reduced in 1798 to 986 officers and privates, exclusive of artillery and rocketmen. The *kacheris* varied in strength from 1,500 to 3,500 men of which one of 3,000 was of Hindus.

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[40] *Official Documents relative to the Negotiations carried on by Tipu Sultan with the French Nation and other Foreign States*, p. 83, Article 6th (printed at Calcutta, 1799).

[41] Only the principal differences between 1793 and June 1798 will be noted.

Macleod says in his *Computation of the Forces of the Sultan* in June 1798 (Forrest's *Selections, Maratha Series*, Vol. 1, Part III, p. 723), that Tipu changed the organization of the army so frequently that "it is often difficult to comprehend them." This appears to be corroborated by Captain (later Sir John) Malcolm's Abstract of Tipu's Forces, dated 16th July, 1798, where the organization of the army is given differently (Martin, *op. cit.*, Vol. 1, pp. 651-670).

This reorganization of the Mysore troops may have been influenced by the reorganization of the Company's army about 1795-96. (Remarks on certain alterations in the equipment or custom of the army since 1790. Colin Mackenzie's *Journal of the March to Seringapatam. Bri. Mus. Add. MSS.*, 13663, folio 10.)

The total number of regular foot including the artillery was 19,160.[42]

The number of the irregular foot is not known, but in view of the 13,500 existing, according to Captain Malcolm, in July 1798, the former strength of 25,000 may not have continued in June 1798.

The regular cavalry was divided into seven *kacheris* instead of three, according to the colour of the horses. There were four instead of six *moukoubs* in each *kacheri*, the strength of each *moukoub* varying from 55 to 700. Each *yuz* consisted of 58 men including horse-keepers. Of the seven *kacheris* one with 500 men was added in 1791 and two others of 737 men in June 1797.[43] The total regular cavalry numbered 3,492 and with an addition of 700 body-guards of the Sultan, made the total of 4,192.

The *silladar* or irregular horse were in six *kacheris* instead of two and numbered 6,000. There were two *kacheris* o Hindus and four of Mahomedans, the former being formed in 1795.[44]

Thus in June 1798 the Mysore army was perhaps 32,252 strong.[45] Macleod observes "I have been informed by a person who had access to the rolls of the army, that its whole strength (in June 1798) was :—

Regular Cavalry	4,000
Irregular Cavalry	6,000
Regular Infantry	20,000

I do not feel any suspicion that there can be a material incorrectness in that statement." These figures are of course "exclusive of *peons* and independent companies of infantry attached to particular forts".[46]

Compared with the army in 1793, the figures for June 1798 exhibit a reduction, particularly in the regular infantry, to the extent of nearly 12,000 men. "The strength of the infantry (in 1798)," writes Macleod,[47] "has increased considerably since the year 1794. This is accounted by the effect of the Sultan's regulations of not admitting any Hindus into his corps, Mahrattas and Rajputs excepted. It may be urged that there ought to be present in his army as many Mahomedans, Mahrattas and Rajputs as there had been in 1794; but the deficiency may be reconciled when it is recollected how much the sources of his recruiting have been limited by the cessions he made in 1792; and that from the army he had at the breaking out of the late, he had lost by desertion a much greater proportion of Hindus than of Mussulmans." Whatever the cause of the diminution in the members, the figures again indicate the incorrectness of the belief, alluded to before, that the Sultan did not reduce his army after 1792.

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[42] Macleod's *Computation* (Forrest's *Selections*, *Maratha Series*, Vol. 1, Part III, p. 722).

[43] *Ibid.*, p. 718.

[44] *Ibid.*

[45] *Ibid.*, p. 722.

[46] *Ibid.*, p. 721.

However, immediately after, in July 1798, Tipu appears to have begun to recruit additional troops. Even in June of that year Macleod was aware of this tendency. "The foregoing computation of the army," he observes,[48] "applies to the state in June last (that is, in 1798), but since that period it has undergone certain changes and arrangements, particularly in the number of infantry corps, being increased by drafts. There is, however, no ground to believe that the actual strength has as yet been augmented, although the increase of the number of corps may be supposed to indicate a design to increase the strength." But there appears to have been an actual increase even in July 1798, according to Malcolm.[49] The actual strength of the army in July 1798 was, according to him[50]:—

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[47] Macleod's *Computation* (*op. cit.*, p. 721). [48] *Ibid.*, p. 723.

[49] Abstract of the present state of Tipu Sultan, dated 16th July, 1798. (Martin, *op. cit.*, Vol. 1, pp. 651-670.) Malcolm was Persian interpreter to the Madras Government at this time. His account of the organization and regulated strength of the Mysore army differs from that of Macleod referred to in the foregoing pages. Although the two accounts describe the Mysore army within about one month of each other, yet they need not be contradictory to each other, specially in view of what Macleod himself. besides many others, says of the frequent changes introduced by Tipu. The accounts have therefore been taken as supplementary to each other.

[50] *Ibid.*, p. 652. The number of pikemen is given in the Abstract as 15,000 which appears to be a mistake for 1;500 which is the number mentioned in the same and in view of the regulated number of pikemen being 2,000.

Regular horse	6,000
Irregular horse	7,000
Regular Infantry	30,000
Guards, Pikemen, *peons*, etc.	13,500
Pioneers	6,000
	62,500

as against the established strength of :—

Regular horse	2,000
Irregular horse	1,200
Regular Infantry	48,000
Guards, etc.	18,000
Pioneers	8,000
	77,200

This augmentation of the forces appears to have been carried on till the beginning of the war of 1799. By the beginning of November 1798 the Sultan is said to have "taken measures to augment his infantry by 8,000 men, and to recruit his cavalry to the number of 30,000. He is also levying 20,000 peons to be used in plundering."[51] According to the estimate of Khan Jehan Khan, one of Tipu's trusted generals, the defeated forces of Mysore on 4th May 1799,[52] numbered as follows :—

In or about the Capital :—	
Infantry	21,500
Cavalry	14,500
	36,000
Outside the State :—	
Forces	12,000
Total	48,000

This figure excludes the killed, missing, wounded and deserters.

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[51] Memorandum in Lord Clive's letter to Lord Mornington, dated 28th November, 1798, based on the intelligence of a person of Seringapatam. (Martin, *op. cit.*, p. 362.)

[52] Beatson, *op. cit.*, appendix XXV.

Compare Kirkpatrick, *op. cit.*, appendix XCIV, footnote.

According to the foregoing discussion the Mysore forces stood in different years as follows[53] :—

		1790.	1793.	1798. June.	1798. July.
Regular Infantry	..	69,000	32,000	20,000	30,000
Artillery ..	..	10,000	....	....	....
Irregular Infantry	..	45,000	25,000	13,500	13,500
Regular Cavalry	..	7,000	7,000	4,200	6,000
Irregular Cavalry	..	12,000	6,000	6,000	7,000
(Pioneers, etc.	..	70,000	[6,000]	6,000	6,000)
		143,000	70,000	43,700	62,500

An attempt may now be made to compute the military expenditure at different times. One of Tipu's letters dated 29th April, 1786,[54] mentions that the monthly pay of a *risāldar* "according to the former regulatoins of the *Jyshe Kucherry* is ten *pagodas* exclusive of an allowance of twelve annas *fulmy* for every man mustered." It is not known what "twelve annas *fulmy*" were equal to.[55] According to the revised regulations of 1793[56] the allowance was withdrawn and a consolidated salary of 30 *kantiroy pagodas* or 90 rupees were given to the *tīpdar* as the *risāldar* was later called, while in June 1798 it was reduced to 25 *kantiroy pagodas*.

Another letter dated 14th June, 1786[57] mentions 5 to 6 rupees as the pay of a boy and 9 rupees as that of an adult belonging to the *Jyshe*. It may therefore be taken that the regular infantryman was paid about nine rupees. As for the pay of the *paideh* or irregular foot, Tipu writes on the 13th of June, 1786,[58] "You will make them a monthly allowance of ten *fanams* per man," *i.e.*, 1 *kantiroy pagoda* or 3 rupees. The pay of the other branches of the army for this period is not known, as also the strength of the army, and it is not possible even to conjecture the expenses at this period.

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[53] The number of pioneers being unknown in 1793 and 1798, it has not been added up in the other years. In June 1798 the number of irregular foot being unknown, the figure for July 1798, when the other branches of the army were augmented, has been assumed.

[54] Kirkpatrick, *op. cit.*, p. 285, No. CCLX.

[55] Kirkpatrick says that he is not sure of the translation of the passage regarding the pay.

[56] Kirkpatrick, *op. cit.*, appendix L.

[57] *Ibid.*, p. 317, No. CCXV.

[58] *Ibid.*, p. 82, No. LXI,

However, as the reorganization of the army does not appear to have taken place before 1793, the scale of pay in 1786 probably continued unaltered till 1793. And the number of troops about 1790 being known, the expenses at that time can perhaps be approximately calculated by taking the average pay of the private and officer alike of the regular infantry at 3 *kantiroy pagodas* a month and of the irregular foot at 1 *kantiroy pagoda* a month.[59] The scales of pay for 1793 are available in great detail for some branches of the army in Tipu's regulations of the year. Macleod's *Computation* and Malcolm's *Abstract* supply the data for 1798, the former being often as detailed as Tipu's Regulations. A comparison of Tipu's Regulations and Macleod's *Computation* indicates that the 1793 rates of pay continued almost unchanged till June 1798.

A study of the foregoing information suggests the following table of the comparative rates of pay in various years. :—

	1790.	1793.	1798 June.	1798 July.
Regular Infantry :—				
Pay of private ..	3.0	5.1	5.1	8.0[60]
Average pay *per capita*	(2.7)	4.8	4.4	..
Irregular Foot :—				
Pay of private ..	1.0	2.0 2.25	{ 2.0 2.25 }	8
Regular Cavalry :—				
Pay of private ..	[3.2]	[5.4][61]	5.4	12[60]
Irregular Cavalry :—	Rs.	Rs.	Rs.	Rs.
Silladars—pay of private	[17.7]	[26][62]	28-30[63]	40-45

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[59] In 1798 when the general scale of pay was probably higher, the pioneers were paid 8 rupees a month.

[60] Net pay.

[61] The Memorandum of December 1790 (*op. cit.*) mentions two kinds of irregular horse, one of which was the *silladars* and the other where the State owned the horse and paid the rider ½ rupee per day for his pay and the maintenance of the horse. The latter was very probably the regular cavalry, and the pay is given as 15 rupees a month.

[62] *Ibid.* This is based on the statement that one kind of irregular horse was where the officer furnished the horse and rider for about ¾ rupee a day. There appears to be little doubt that these were the *silladars*.

[63] Kirkpatrick says (*op. cit.*, appendix p. xciii) that 30 rupees were the usual average pay of men riding their own horses,

The foregoing table needs some explanation. The figures in brackets are those suggested as the pay, wherever definite figures are not available. Those without brackets are found in Tipu's Regulations for 1793, Macleod's *Computation* for June 1798 and Malcolm's *Abstract* for July 1798. The average pay is computed from the first two of the foregoing authorities, and denotes the average for officers and privates, and non-combatants, composing a regiment. The suggested scale of pay, both average and for privates, is based on the ratio between the established salaries as given by Tipu, Macleod or Malcolm; and the figures for the regular foot being more exactly available than for the others, the ratio between them is taken as indicative of the proportion between salaries in the other branches. Regarding the figures for July 1798, the salaries for the regular foot and horse are said to be *net*, while those for the irregular foot and horse, are not net. "I stile it *net* pay," says Malcolm,[64] "because all the troops have a nominal pay, exceeding considerably what they actually receive, a circumstance which arises from the difference of exchange in the *circar* payments and in the Bazaar."

Macleod[65] also mentions stoppages in the pay, but it is doubtful if these are the same as the difference mentioned by Malcolm. Buchanan probably referred to what Malcolm alluded when he wrote[66] "when he (Tipu) was about to pay his troops, the nominal value of each coin was raised very high and kept at that standard for about ten days; during which time the soldiers were allowed to pay off their debt at the high valuation. After this the standard was reduced to the proper value." However, this may perhaps explain to some extent the difference between the figures for June and July, one being net, and the other given in the foregoing table, not being net.

In view of the lack of more reliable and definite data the foregoing figures, though far from exact, can perhaps form a rough basis of calculation.

Thus the expenses of the army in the form of pay in 1790 would be :—

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[64] Martin, *op. cit.*, p. 653, footnote.

[65] Forrest, *op. cit.*, p. 721.

[66] Francis Buchanan, *Journey from Madras through the Countries of Mysore, Canara and Mysore,* 1807, Vol. I, p. 129,

		Kantiroy Pagodas (per month).
Infantry :		
Regular	2,12,300	
Irregular	45,000	
		2,57,300
Cavalry :		
Regular	22,100	
Irregular	70,400	
		92,800
		3,50,100

or Rs. 10½ lakhs.

One important item has been omitted and that is the pay of 70,000 pioneers. In July 1798 the pioneers were paid, according to Malcolm, 8 rupees, and if they were paid in 1790 at least 4 rupees, that would cost about 2.8 lakhs of rupees per mensem, bringing the total monthly expenditure on salaries to 13.3 lakhs of rupees.

After 1792 the expenses and the number of troops were reduced. The monthly expenditure on 32,000 regular foot including 2,000 artillery was Rs. 4,54,800.[67] Of the 25,000 garrison troops, 15,000 were stationed in the provinces and paid at 2 *kantiroy pagodas* each for forty days, while the remaining 10,000 troops stationed at the capital were paid at

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[67] According to Tipu's Regulations the expenses would be Rs. 6,67,000 per mensem, the details being :—

	Rs.
For four *kacheris*	5,43,513
For the fifth *kacheri*	74,379
French troops	24,537
Three extra *tips*	15,864
Pioneers, drivers, etc.	8,820
	6,67,000

The fifth *kacheri* was paid higher salary being the Sultan's favourite corps.

As already pointed out the regulated strength and expenditure do not seem to have actually existed.

2¼ *kantiroy pagodas* each, probably for a month of 30 days.[68] The garrison would therefore cost per month of 30 days Rs. 1,57,500, the provincial garrison involving Rs. 67,500, and that at the capital Rs. 90,000.[69]

As regards the cavalry, the Memorandum of December 1793 indicates that the regulars were paid 15 rupees a month, and the pay of 7,000 regular horse would, therefore, come to Rs. 1,05,000. Six thousand *silladars* at Rs. 26 each per month cost Rs. 1,56,000.

It is uncertain how the predatory horse, 8,000 in number, were paid. Kirkpatrick thinks that the officers received a regular salary like the *silladars* and presumes that the men also must have received pay during peace, although during war they were allowed to retain the booty they obtained in lieu of pay.[70] It is, however, difficult to make even a guess regarding these troops, and so they may be left out of account for the present.

Thus in 1793 the cost of the pay of the troops per month of 30 days was :—

	Rs.	Rs.
Infantry :		
Regular	4,54,800	
Irregular	1,57,500	
		6,12,300
Cavalry :		
Regular	1,05,000	
Irregular	1,56,000	
		2,11,000
Total ..		8,23,300

In June 1798, when there appears to have been a further reduction of troops, the expenses probably stood as follows :—

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[68] Kirkpatrick, *op. cit.*, appendix p. cii, footnote 23. Kirkpatrick does not say if the garrison at the capital also was paid at 40 days a month ; as he mentions it only with reference to the provincial garrison it is probable that they were paid for 30 days.

[69] *Ibid.*, appendix p. civ.

[70] *Ibid.*

	Rs.	Rs.
Infantry :		
Regular	2,64,000	
Irregular	85,860	
		3,49,860
Cavalry :		
Regular	68,040	
Irregular	1,80,000	
		2,48,040
Total ..		5,97,900

Six lakhs of rupees seem to have been the approximate monthly expenditure in June 1798.

From July 1798 the number of the troops was increased and very probably the expenditure also was increased. But the details regarding the pay and particularly with regard to the exact significance of what Malcolm calls 'net pay ', are not sufficient to permit even an approximate calculation of the expenditure after July 1798.

There is one important consideration to be borne in mind while dealing with the foregoing estimates, and that is, that the pay does not appear to have been issued regularly or for full twelve months in the year. One of Tipu's letters of 11th of September 1785[71] refers to the distress in Kamaruddin's division for want of pay, and to the dispatch of 20,000 pagodas for distribution. Another letter[72] vividly describes the state of affairs: "we have received your letter acknowledging the receipt of 21,000 *pagodas* and representing that so far from that sum sufficing for the payment of all your troops, it is inadequate even to the payment of the regular infantry." In 1799,[73] a Mysore predatory horseman captured by the British complained of Tipu's very sparing distribution of pay.

There was another kind of irregularity profitable to the State. Hyder is said to have generally calculated 40 days as equal to a month, thus paying only 9 months in the year. The same system seems to have been followed by Tipu. A letter to

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[71] Kirkpatrick, *op. cit.*, No. CXIII.

[72] *Ibid.*, No. LXX, Letter dated 23-6-1786.

[73] Malcolm's *Diary. Bri. Mus. Add. MSS.*, Vol. 13664, folios 31-33.

Raja Ramachandar[74] mentions that the Sultan ordered the *amil* of Yusufabad to pay the *ahmedies* at 36 days as equal to a month, and Raja Ramachandar asks Tipu if he has also to follow the same practice. This suggests that the usual month for purposes of pay was more than 36 days, perhaps 40 as before, and that the *ahmedies* were the favourite troops of the Sultan, being composed of forcibly converted youths, to whom the Sultan showed special kindness. Tipu rejected this proposal, but would probably have complied if it had been a question of lessening the number of months, an operation advantageous to the State. Writing in 1798 Macleod observes[75] that the month for salaries was nominally said to consist of 40 days. It is, therefore, probable that before 1792-93 the troops were paid once in 40 days, *i.e.*, only nine months in the year.[76]

In the latter part of Tipu's reign, things appear to have taken a more irregular turn. Referring to June 1798, Macleod writes,[77] "Although the month is nominally said to consist of 40 days, there is no actual account kept of regular dates for payment of the troops, the intervals between issues of pay being arbitrary according to the Sultan's pleasure from 40 to 55 days." This means that the troops were paid between 6½ and 9 months in the year. It is not known when this irregularity crept in. Wilks believes[78] that about 1795 the army was receiving only seven months' pay and began to show discontent. As regards discontent it is almost certain that at least before 1792 the army was contented and loyal. For Rennel observes[79] after the war of 1790-92 "It was reserved for the Mysoreans to put our prowess and discipline to the test," while another contemporary British officer[80] remarks in 1794 that "the discipline and fidelity of his (Tipu's) troops in the field, until their last overthrow were testimonies equally strong of the excellent regulations in his army." If the regulations for paying only seven months in the year had been adopted before 1792, there would have been in all probability discontent. Moreover, the finances of Mysore do not seem to have been in a bad condition till 1792. There is another circumstance which indicates the introduction of the new system about 1792-93. Tipu is said to have distributed among his servants the burden of the 330 lakhs of rupees he had to pay in 1792 to the allies, and the Mysore army had its share of 60 lakhs to pay.[81] Perhaps the only easy way of collecting the amount would be by stoppages in the pay. About 1793[82] the monthly expenditure on the pay of the troops appears to have been 8¼ lakhs of rupees, and it would, therefore, take about 7 months to pay to make up 60 lakhs. The army was being ordinarily paid only 9 months. To throw the whole burden of the contribution on one year would reduce the salary of the army to two months. Such a step would obviously be impolitic and impracticable. Wilks[83] is, therefore, perhaps correct in believing that the issues of pay were reduced to seven in the year until the contribution should have been realized. This would distribute the burden over about three and half years.

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[74] Kirkpatrick, *op. cit.*, No. CCLIX, dated 19th September, 1786. Raja Ramachandar was Tipu's officer in charge of the Bangalore division.

[75] Macleod's *Computation* (*op. cit.*).

[76] Wilks, *op. cit.*, Vol. II, p. 262. Wilks observes that when in 1792 the method of levying a portion of indemnity on the army was considered, it was calculated that the army received or ought to have received 10 monthly payments in the year. But it is more probable that, as the foregoing discussion indicates, the army was paid for 9 months only.

[77] *Op. cit.*

[78] Wilks, *op. cit.*, Vol. II, p. 288.

[79] *Marches of the British Armies in the Peninsula of India*, p. 110.

This arrangement probably continued at least till about the beginning of 1796. It is, however, doubtful if it was not pursued for some time longer. . From Wilks[84] it appears that in 1796[85] the army continued to receive only seven months pay in the year and began to evince considerable discontent and that the Sultan therefore introduced the system of granting jaghirs, reckoning the pay at ten months. He adds[86] "the

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[80] Lieut. E. Moore's *Narrative of the Operations of Capt. Little's Detachment*, p. 208.

[81] Wilks, *op. cit.*, Vol. II, pp. 262-63. Tipu agreed to contribute 110 lakhs, the army 60 lakhs and the people 160 lakhs.

[82] *Supra* page 42.

[83] *Op. cit.*, Vol. II, p. 262 ; also p. 288.

[84] *Op. cit.*, Vol. II, p. 288.

[85] Wilks does not definitely mention the date but the context indicates this year.

[86] *Op. cit.*, Vol. II, p. 289.

Silladars without exception embraced the arrangement, and many of the stable horse and infantry."

However it appears more likely that the granting of jaghirs was introduced about the beginning of 1798. Malcolm observes in July 1798[87] that the system of assigning lands to the army was a great change in the Mysore revenue system lately introduced. He adds[88] that in February the Sultan detached " Banki Nabab, Reza Saheb, in one direction, and Meer Saduk in another, in order to distribute the lands to the jamedars of Sillahdar horse agreeably to the new system of supporting them that he had resolved upon." There is no reason to believe that the scheme was extended to the *Silladars* some time after it had been introduced in the other branches of the army; and especially in view of the fact that the *Silladars* seem to have embraced the arrangement more readily than the others, it is likely that the scheme was introduced for the first time in the beginning of 1798.

As already noted, the introduction of the new system said to have been accompanied by raising the monthly payments to the troops from seven to ten.[89] It may be asked if the Sultan would have thus increased the expenditure, particularly in the face of ever worsening finances. But the increase is very probable because the retrenchment in the payments had been only a temporary expedient, the number of troops in the beginning of 1798 had been much reduced, so that even with this liberality the cost was probably not expected to be more than formerly; and Tipu had hostilities in view and therefore had to keep his army contented and loyal. It is not, therefore, improbable that from 1798 the troops received salary for 10 months in the year.

On the basis of the foregoing discussion it follows that the expenditure on the pay of the army in 1790 was 13.3 lakhs of rupees a month, and there were 9 such monthly payments; in 1792-93 it was 8¼ lakhs of rupees paid for 7 months; and in 1798, there were 10 monthly instalments of 6 lakhs of rupees each. This gives the following figures:—

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[87] Malcolm's *Abstract.* (Martin, *op. cit.*, Vol. I, pp. 655-656.)

[88] *Ibid.*, p. 656.

[89] Wilks, *op. cit.*, Vol. II, p. 288.

	Rupees in lakhs.
1790	119.7
1792-93	55.25
1798	60.00

The latter two figures exclude the expenses on the pioneers etc., as their number in those years is not known. In July 1798, according to Malcolm,[90] there were 6,000 pioneers and 8,000 Karnatic *peons* paid 8 and 5 rupees respectively. If the same number existed in 1792-93 and June 1798, there would have been additional expenditure of 6.1 and 8.8 lakhs, bringing the total to :—

	Rupees in lakhs.
1792-93	61.3
1798	68.8

There are two contemporary estimates of Tipu's military expenditure, for the foregoing period. A Memorandum of December 1793[91] gives the following figures :—

		Rs.
30,000.	*Regular Infantry* at Rs. 120 as average annual pay per head	36,00,000
7,000.	*Regular Cavalry* at Rs. 300 as average annual pay per head including feeding, purchasing or rearing each horse	21,00,000
6,000.	*Irregular Cavalry* at Rs. 260 as average annual pay per head including feeding, purchasing or rearing each horse	15,60,000
2,000.	*Artillery Men* attached to the Infantry at Rs. 130 each	2,60,000
	Repairs of forts, making up stores and pay of artificers and camp lascars	....
	Total Rs. ..	83,36,000

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[90] Malcolm's *Abstract.* (*Op. cit.*, p. 652.)

[91] *Bri. Mus. Add. MSS.*, Vol. 13659, folio 84.

In comparing this estimate with mine, it must be remarked that the item for repairs of forts, etc., should be omitted from this estimate, as only the pay of the army has so far been considered while from that arrived at in the foregoing pages should be excluded the cost of the pioneers, etc., and of the irregular foot, both of which find no place in the estimate of the Memorandum. Moreover, the latter estimate appears to have calculated the pay for 10 months instead of seven. For while it gives the pay of the irregular horsemen at $\frac{7}{8}$ of a rupee per day or 26 rupees for a month,[92] in giving the total expenses of the irregular horse, it estimates each trooper's salary at 260 rupees.[93] This suggests that the author of the Memorandum was not probably aware of the seven months' arrangement. Now to compare the two estimates—

	Estimate in the Memorandum. For 10 months.	Estimate in the Memorandum. For 7 months.	Estimate arrived at in the foregoing pages.
	Rs.	Rs.	Rs.
Regular Infantry	36,00,000	25,20,000	31,83,000
Artillery	2,60,000	1,82,000	
Regular Cavalry	21,00,000	14,70,000	7,35,000
Irregular Cavalry	15,60,000	10,92,000	10,92,000
Total ..	75,20,000	52,64,000	50,10,000

The great difference in the expense of the regular cavalry is explained by the fact that the Memorandum calculates the cost of feeding, purchasing, etc., of the horses, which has been omitted in the other estimate. If half of the 30 rupees assumed by the Memorandum as the expense of each horse and its rider is taken as the cost of feeding, etc., the horse, then there will be found a remarkable identity in the figures for the regular as of the irregular cavalry in the two estimates. As regards the expenditure in 1798 Macleod writes[94] "His marching army including officers, may be reckoned to cost 20,00,000 (star) pagodas." The value of the star pagoda at this time is uncertain. "It frequently happens," writes General Wellesley in 1803,[95] "that in the bazaar, the star pagoda exchanges for 4 rupees, and at other times for not more than 3." The Memorandum of December 1793[96] takes the pagoda as equal to 3½ rupees which was also the value at which the coin was issued to the Company's troops in 1803.[97] At the latter rate the expenditure on the marching army according to Macleod was 70 lakhs of rupees. This appears to include all branches of the army. With this may be compared the estimate of 68.8 lakhs.

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[92] *Idem.*, f. 80.

[93] *Idem.*, f. 84.

[94] Macleod's *Computation.* (Forrest, *op. cit.*, appendix C.)

The comparisons show that the figures arrived at in the preceding pages probably approximate to the actual expenditure. The trend of the movement in expenditure is interesting. Between 1790 and 1793 the monthly expenses fell from about 13.3 lakhs to nearly 8½ lakhs, although the number of the troops was reduced by nearly half.

The discrepancy may perhaps be explained by two factors. First, the greater part of the reductions were in the lower-paid branches of the army. Secondly, there was probably an increase in the rates of pay. In 1798 the reduction in the strength of the army was closely followed by a decrease in the expenditure. After 1798 it is likely that the number as well as the expenses of the army began to move up.

Before other items of military expenditure are considered mention must be made of a common practice of ill-administered governments which Tipu appears to have adopted late in his reign, *viz.*, the granting of jaghirs in lieu of pay. Jaghirs were usually given when a government, because of its weak and loose administration, could not pay regular money salaries. This appears to have been the condition of Mysore specially near the end of Tipu's rule, and as already observed, the system was introduced about the beginning of 1798. In the month of February of that year, Banki Nawab, Reza Saheb and Mir Saduck are reported to have assigned lands to the *Silladars.*[98]

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[95] Wellesley to Stevenson, 4th October, 1803. (Gurwood's *Dispatches of the Duke of Wellington*, Vol. II, p. 375.)

[96] *Bri. Mus. Add. MSS.*, Vol. 13659, folio 84.

[97] Wellesley to Kirkpatrick, 14th October, 1803. (Gurwood, Vol. II, p. 419.)

[98] Macleod's *Computation* (*op. cit.*), *Supra* p. 46.

The grant of a jaghir involved the transter of a certain portion of the public revenue to the grantee.[99] The collection of revenue appears to have been very loosely carried out so that neither was the collection made in full nor was the revenue scrupulously remitted to the treasury because of the corruption of the officers. Moreover, it is an established fact that a State generally takes much less from the cultivator than a private landlord would. Therefore while assigning lands Tipu is said to have estimated their value at 25 per cent more than what they yielded to the State. In 1794-95 Tipu had increased his general land revenue demand by 37½ per cent. It seems clear that new jaghirdars must have been faced with the problem of realizing a greatly increased revenue demand. Wilks disapprovingly observes,[100] that "the calculation was made not on the old rates, but on those recently established, and the actual excess above the ordinary value at which the jaghirs were estimated to the troops was exactly 71⅞ per cent."

This remark is liable to be misunderstood. Tipu appears to have been justified in calculating the revenue of lands in this way. For the excess valuation could not in fact be more than 25 per cent at least so far as the grantee and grantor were concerned. For before lands were assigned the assessment on all lands was augmented by 37½ per cent. That is, the State was entitled to the increase and the revenue from the lands was, therefore, 37½ per cent more; and any grantee would become entitled to this increase. It was therefore reasonable that the increased value of the land was taken as the basis of calculation.

But the State did not take into account another consideration. As the estimate seems to have been made, according to Wilks, on the gross value of the lands, the collection charges were saved to the State by assigning the lands and as the grantee was also to incur the same charges, there ought to have been some reduction in the basis of valuation.

However, "such allotments could be made only to corps, troops or companies and not to individuals, but the acceptance was prudently permitted to be optional."[101] The *silladars* appear to have taken advantage of the scheme. "Jaghirs of generally half their allowances," writes Macleod,[102] "have been given to the sillahdars in situations within 50 miles of Seringapatam; they remain dispersed among their villages by which means they are enabled to take the greatest care of their cattle and to superintend their farms." That the other branches of the army did not take much advantage of the arrangement is probable. For a few days after the fall of Seringapatam in 1799 Macleod[103] remarks that the jaghirs amounted to about five lakhs of *kantiroy pagodas* or fifteen lakhs of rupees. The *silladars* are reported to have been given jaghirs to the extent of half their pay, *i.e.*, equal to five months' salary in the year. This means that of the lands worth 15 lakhs of rupees 9 lakhs were taken up by the *silladars*, while the rest of the army shared the remaining 6 lakhs. This indicates that the scheme was not much favoured by the army excluding the *silladars.*

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[99] The following account is mainly based on Wilks, *op. cit.*, Vol. II, pp. 288-289.

[100] *Ibid.*

In addition to the saving in the expenses of collecting revenue, and to the 25 per cent premium at which the jaghirs were granted there was another important advantage gained by the State from this scheme. The embezzlements in the revenues of the lands to the amount of the assignments were henceforth saved to the State. According to Macleod[104] the embezzlements were about 36 per cent of the revenue and by assigning lands to the value of 15 lakhs of rupees, the State gained more than 5 lakhs of rupees.

There are some other items of expenditure to be considered under the head of defence. One of them was the provision for wounded and disabled soldiers and their families. One of Tipu's letters of the 9th August 1785[105] refers to the proper and careful treatment of wounded soldiers.[106] Another letter dated 17th September 1785, mentions regulations respecting the wounded and says that Rs. 1,000 were sent as compensation to the wounded in a regiment sent against Coorg.

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[101] *Ibid.*

[102] Macleod's *Computation* (*op. cit.*).

[103] *Letter to General Harris*, dated 22nd May, 1799.

[104] *Ibid.*

[105] Kirkpatrick, *op. cit.*, p. 132, No. CI.

[106] Tipu to Mir Zynul Rabidin. *Idem.*, p. 150, No. CXVII. Also Tipu's letters to Mirza Khan, 16th September, 1785 and to Fazl Ali Khan, 5th May, 1785. *Ibid.*, Nos. CXIX and CCLXIX.

"The Zuckum Puttee or compensation to the wounded," observes Kirkpatrick,[107] "is a custom pretty general in the native armies of India." Tipu's proclamation of 1798 to his people runs[108] "To the widow and children of every man who shall fall in the battle, a maintenance equal to a fourth of the share so accruing (to the soldier), and of the pay of the deceased martyr.

The widows and children of men who merely die on service, one-quarter of a gold fanam daily (about two and a half rupees a month)."

Although perhaps these promises were not performed as the Sultan died the very next year, yet the foregoing details indicate that provision for the wounded soldier and his family was a probable item of expenditure from the beginning of the Sultan' reign.

Another item involving greater expense was the provision of munitions, transport, and commissariat. An account of about 1790[109] gives the following figures :—

Elephants	700
Camels	6,000
Horses	11,000
Bullocks and cows	4,00,000
Buffaloes	1,00,000
Sheep	6,00,000
Firelocks	3,00,000
Matchlocks	3,00,000
Swords	2,00,000
Cannon	2,000

These figures may be exaggerated, but they indicate the extent of the establishment. As regards bullocks and other means of transport, the Mysore army from the time of Hyder had been famous for the efficiency, excellence and number of its draught cattle.[110] In this respect the Company's army was markedly inferior. In the war of 1790-92, though it employed fewer troops than Tipu did, and employed no less than 32,000 bullocks, its transport service were so bad that Lord Cornwallis had actually to blow up his guns and ammunition when he retreated from Seringapatam in 1791. Writing in July 1798, Malcolm observes[111] that Tipu has "as many elephants, camels and draught and carriage cattle as he even can require."

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[107] *Idem.*, p. 150.

[108] Wilks, *op. cit.*, Vol. II, p. 293.

[109] *Home Miscellaneous*, Vol. 251, p. 299.

[110] Compare Josiah Webbe's Memorandum for General Harris dated 6th July, 1798. (Martin, *op. cit.*, Vol. I, pp. 76-77.)

As for the stores and provisions they appear to have been equally huge. After the peace of 1784 the Sultan is said to have stored Seringapatam with provisions for 100,000 for 12 months and likewise other forts according to their importance.[112] In 1791 "large magazines of military stores which had been amassed in those places (Dharwar, etc.) at a vast expense fell into the hands of the captors."[113] Likewise when Bangalore fell in the same year "the quantity of stores of all sorts (was) prodigious, shot innumerable, and powder about 20,000 barrels."[114] In 1799 on the fall of Seringapatam were found "in all 929 pieces of ordnance....There were 424,000 shot, 520,000 pounds of gunpowder, and 99,000 muskets and carbines, etc.... within the fort there were eleven large powder magazines; armouries for making and finishing small arms, 2 foundries for cannon;....4 large arsenals; and 17 other storehouses containing other accoutrements, swords and other articles; besides many granaries abundantly stored with provisions of every kind."[115] These extracts sufficiently indicate the vast stores accumulated by the Sultan since his accession in almost every fort. The expenses on them can be comprehended when it is remembered that when the Company had fewer forts to garrison in the Madras Presidency and that too probably not on so large a scale as Tipu, it is said to have cost the Company about 3 lakhs of *pagodas* per annum ; "it is also to be observed that during the late war (*i.e.*, of 1784) little cash was expended on making up stores. During the present war (*i.e.*, of 1790-92) nearly four lacs of *pagodas* have been expended on the making up of stores (this was in July 1791). If the war was therefore to cease our arsenals would require very little recruiting. I affirm as a fact that exclusive of powder 25,000 pagodas annually will keep up the supply of stores made in this country."[116] This passage is very suggestive. The Company had less army than Tipu and was only one of three powers waging war against Mysore. Moreover it was not preparing for war with as much zeal as Tipu. Being the victor in 1792, a vast sum of stores fell into its hands as well as those of its allies, and that vast quantity the Sultan lost and had to make up. Both before 1790[117] and after[118] Tipu is said to have made vast preparations for war. Considering all these, it appears reasonable to assume that Tipu spent at least at the rate of one or two lakhs of *pagodas* on making stores.

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[111] *Ibid.*, p. 652.

[112] Charles Stuart's *Catalogue of the Library of Tipu Sultan*, Introduction p. 52. Also *Asiatic Annual Register*, 1799. *Characters*, p. 3.

[113] Governor-General to the Court, 7th September, 1791. (*Home Miscellaneous*, Vol. 251, p. 49.)

[114] Letter supposed to be received from Mr. Fordyce, dated 21st April, 1791. *Idem.*, p. 476.

Also see J. H.'s letter to Rev. M. S. Hargrave dated camp near Nellore, 12th August, 1791. (*Idem.*, p. 527.)

[115] Beatson, *op. cit.*, p. 139. Also General Harris to the Governor-General, 22nd May, 1799.

There is another item of expenditure. So far no provision has been made for the expenses of replacing or paying for the horses killed in war. The State had to replace the stable horses killed, and pay compensation for the *silladar* horses. In fact, it appears to have been a condition of service that "if a horse belonging to the irregular cavalry is killed on service, the circular (is) to pay a stated price" ;[119] and the price is said to have been 250 rupees per horse. In 1791 vast numbers of Mysore horses and cattle died for want of forage when the allies over-ran the country,[120] and because of the great inclemency of the weather.[121] These expenses, coupled with the expenditure on the purchase of horses when the number of the cavalry was increased, must be taken into consideration.

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[116] Letter from Madras dated 15th July, 1791. (*Home Miscellaneous*, Vol. 251, p. 19.)

[117] Sir A. Campbell to Lord Cornwallis, 6th October, 1787. (*Idem.*, Vol. 248, p. 326.)

[118] Governor-General to Henry Dundas, dated 7th June, 1799. (Martin, *op. cit.*, Vol. II, p. 40.)

[119] Malcolm's *Abstract.* (*Ibid.*, Vol. I, p. 653).

[120] Private letter from Tellicherry, dated 25th July, 1791. (*Home Miscellaneous*, Vol. 251, p. 504.)

There is one more branch of defence which requires consideration, *viz.*, the fleet. One of the Sultan's letters of 1786[122] is addressed to the superintendent of the fleet, and orders are issued to get the vessels coppered. Commenting on this letter, Kirkpatrick observes[123] "I am ignorant of the amount as well as of the nature of the Sultan's naval force at this period. If we are to judge by the designation (armada) which he has thought proper to apply to it, we might be led to conclude that it was of considerable strength. But no inference can be safely drawn from so slight a circumstance while, on the other hand, there is more than one reason for believing that this marine must have been very insignificant at the time referred to. In the first place, it is pretty certain that Hyder Ali bestowed little or no attention on this object; and it is equally clear that his successor had not hitherto had either time or means to do much in pursuit of it. Besides nothing was either known or heard of his armada during the war which ended in the partition treaty of 1792; and though after that event, he applied himself seriously to the formation of a respectable navy, he had happily not been enabled to effectuate his purpose, before his restless and impatient spirit plunged him into another premature war; in the short course of which as little was heard of his navy as during that which preceded it."

These observations are perhaps to a great extent true. Before 1792 the fleet is said to have been considered mainly as a protection against pirates.[124] But it is probable that even before 1792 Tipu had commenced to build men of war. Dirom[125] remarks that in October 1791 in the "Fortified Island" *i.e.*, Honver was found complete material for shipbuilding, and a ship of sixty guns was almost complete when it was scuttled and sunk at the beginning of war.[126]

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[121] Extract from letter dated camp between Hosur and Rayacotta, 10th August, 1791. (*Idem.*, p. 27.)

[122] Letter to Mir Ghulam Hussain, dated 24th September, 1786. (Kirkpatrick, *op. cit.*, p. 414, No. CCCLXXI.)

[123] *Ibid.*, p. 415.

[124] Wilks, *op. cit.*, Vol. II, p. 267.

Lord Valentia observes that "Tipu built ships of 500 tons and chiefly for the purpose of collecting his revenue from the numerous tributary Rajahs who lived along the coast." (*Travels in India*, Vol. I, p. 454.)

[125] *Cornwallis' Campaign*, p. 107.

After the defeat of 1792 the Mysore sovereign turned his thoughts seriously to building up a navy. The marine department appears to have been placed in charge of the board of commerce till 1796.[127] Perhaps in September of that year[128] was established a new admiralty department, and a new code of regulations was issued.[129]

The chief officers of the admiralty were called *mir yumms* and were ordinarily resident of the capital, although some of them were stationed at the principal ports of dock-yards. Next to them in rank were *mir bhurs* or admirals serving afloat, two of them being assigned to a squadron of four men of war. Forty ships were immediately ordered to be constructed so much so that the Sultan says in his ordinance they were thereby consigned to the care of the *mir yumms.*

The ships were divided into three *kacheris* or departments, namely, those of Jumulabad, Wajidabad and Majidabad. The three departments were to consist of 12, 14 and 14 ships respectively. Twenty of these ships were to be line of battle and twenty large frigates.

The ships were divided into 10 squadrons or fouz of four ships each, and each squadron had two admirals (*mir bhurs*) who were paid 150 rupees a month including allowance. Ten more admirals were with the Sultan to receive instructions, and were paid according to their status. So did the pay of their superiors, the *mir yumms*, differ according to their rank.

Every ship of the line had 346 men of all denominations. There were four *sirdars* or officers, corresponding to the captain and the three lieutenants in a modern man of war. Of the crew the combatants consisting of musketeers and gunners, were placed under two different *tipdars.* The *tīp* of musketeers was divided into four *yuz,* while the gunners were divided into two *yuz* of 39 men each. There were also 2 gangs of *jowks* of 61 seamen, besides 10 carpenters and smiths and 7 officers of staff.

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[126] This disproves the belief that all the ships of Hyder and his son were built in Mangalore. (*Manual of the Madras Presidency*, Vol. III, p. 467.)

[127] Kirkpatrick, *op. cit.*, appendix p. LXXVIII.

[128] Macleod believes that the Marine Department was formed in May 1797. (Forrest, *op. cit.*, p. 723.)

[129] The following account is mainly based on Tipu's marine regulations as given in Kirkpatrick, *op. cit.*, appendix pp. LXXVII–XCII.

Each of the 20 frigates comprised 180 men, which included a *tīp* of 63 musketeers, a *yuz* of 28 gunners and a gang of 71 seamen, and 8 miscellaneous officers.

Besides, twelve small vessels called *nugs* in the nature of transport ships were also to be constructed.[130]

The rank and file of the navy were paid salaries, while the officers received in addition allowance calculated upon the number of men serving under each officer. This allowance operated as a stimulus to the officers to keep their corps as complete as possible. When afloat both men and officers were given rations also.

The expenses in the nature of pay and allowances were :—

	Rs.
For each battleship	4,415
For each frigate	2,425

The total expenses on this score for 20 battleships and twenty frigates amounted monthly to Rs. 1,36,800 and annually to Rs. 16,40,000.

In addition there was expenditure on dock-yards in Jumulabad, Wajidabad and Majidabad, and this involved Rs. 44,280 per annum, bringing the total expenses to very 16½ lakhs of rupees.

But how far these proposals were carried out is uncertain. In his letter to Tipu, dated 4th March 1798,[131] Admiral Sercey, the commander of the French Naval forces in the Indian seas, refers to the dispatch of naval officers to help the Sultan in building his fleet. Likewise General Malartiqui mentions in a letter to the Sultan, dated 7th March 1798,[132] the pay of the naval and military officers he sent to Mysore. Of June 1798 Macleod remarks that " The Sultan is supposed not to possess above 8 or 10 vessels, which are chiefly employed in transporting pilgrims to and from Mecca."

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[130] A great obstacle to the development of a navy was the want of a good harbour. Mangalore, the chief Mysore port, was too shallow. (Vide *Manual of Madras Presidency,* Vol. II, p. 147. Also *Valentia's Travels,* Vol. I, p. 455.)

[131] *Official Documents relating to the Negotiations, carried on by Tipu Sultan with the French Nation, etc.,* p. 103.

[132] *Ibid.,* p. 116.

It is therefore likely that a considerable sum of money was being expended on this branch of defence.

Although it is not possible to conjecture the expenditure on all the foregoing items, yet they must be taken into account while considering the military expenditure of Mysore.

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SOME STAGES OF THE PLACENTATION IN *VESPERUGO LEISLERI* (KUHL).*

BY L. S. RAMASWAMI.
(Department of Zoology, Central College, Bangalore.)

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* Thesis submitted in partial fulfilment of the requirements for the M.Sc. degree of the Mysore University.

INTRODUCTION.

The object of this paper is to examine the histological details and the disposition of the fœtal envelopes during certain stages of development of the locally occurring smaller bat Vesperugo (Microcheiroptera). The study is restricted to a few stages since it was not possible to secure a regular series in development. From a time little prior to the appearance of the amnion as a cavity within the epiblastic mass, right up to the stage where a well-formed placenta, which is no more augmented by further addition, will form the subject-matter of this paper.

This work was undertaken at the suggestion of Dr, A. Subba Rau, B.A., D.Sc., and Professor C. R. Narayan Rao, M.A. I take this opportunity of acknowledging my thanks to the numerous acts of kindness which I have received from time to time from both. Bulk of my slides have been examined by them and throughout my investigations I have received constant help and guidance. In regard to literature I have been greatly helped by Dr. S. G. M. Ramanujam, M.A., Ph.D. and also the authorities of the Indian Museum, Calcutta, and to both my warmest thanks are due.

HISTORICAL.

The subject of placentation in bats has been engaging the attention of workers from early times. As early as 1818, Emert and Burgaetzy (1818) described the gravid uterus, the placenta and ovary of Fledermäuse. Ercolani (1879) working on the bats, attributed the origin of the allantoic villosities to the fœtus and considered the mass of fœtal placenta as having a maternal origin. He did not describe the vascularisation of the placenta. Frommel† and van Beneden (1888*b*) independently published their observations. They attributed a maternal origin to the trophoblast and it was only later when M. Duval (1897) published his account, that van Beneden changed and corrected his views.

While these early investigators worked so exhaustively on the smaller bats, Göhre (1892) published an article entitled " Dottersac und placenta von Pteropus edulis " and this seems to be the only work on this frugivorous bat. He described the placenta as composed of two parts: the fœtal consisting of chorionic villi which are at the beginning thick with slightly hollowed out core and the maternal part a network of vessels into which the chorionic villi penetrate. This network could be divided into three parts: a sub-chorial part, a central part and lastly the deeper zone. The endothelium of these vessels is intact and only disappears in the capillaries. Further according to Göhre (1892), between the delimited maternal and fœtal tissues there is a continuous layer—probably corresponding to the plasmodiblast of van Beneden (a feature also noticed in *Myotus murinus* by Frommel). Göhre also describes the disappearance of the uterine epithelium and the paucity or the absence of glands in the region where the future placenta is to be formed. He also notices the complete disappearance of the cavity of the umbilical vesicle. These points are important in comparing the bigger bats with the smaller ones and are dealt with in the appropriate place in this paper.

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† Frommel, *Wiesbaden*, 1888.

The latest works are those of Sansom (1932) on the early stages of the American bat *Molossus* and Kemperman (1929) on the placenta of *Miniopterus*, and Da Costa (1920) on *Miniopterus*. In this connection the work of P. Nolf (1896) on the placentation of *Vespertilio murinus* may be mentioned and the nomenclature followed in this paper is according to Nolf.

MATERIAL AND METHOD.

The locally occurring small bats were collected from time to time and the uteri in various stages of gestation were fixed in Bouin's picroformol, acetic alcohol, acetic alcohol-sublimate, neutral absolute alcohol and Flemmings weak fluid. All of them have given very good results. Injections with warm gelatine mass into the arterial system did not prove very successful. Longitudinal, transverse and tangential sections with reference to the uterus and placenta, all 8—10 microns in thickness, were cut; and various stains—hæmatoxylin (Ehrlich), hæmatoxylin-eosin, Mayers hæmalum, picro-indigo-carmine and Pasini—were employed. One point of technical interest must be mentioned. The uteri containing early stages were not slit open to permit the penetration of fluids, while the advanced ones suffered a slit. They were all graded from 10 per cent alcohol; this is essential in order to avoid the entry of dissolved air from the aqueous fixatives into the uteri, since higher percentage of alcohols do not dissolve in them the air. In order to get good sections this procedure is very essential.

BREEDING SEASON.

The breeding season when prolific fecundity occurs seems to be between June and early August. One is sure to find pregnant forms during this part of the year. It is also just possible that there is another season when these begin to breed, for, I have noticed the occurrence of pregnant uteri during the early part of January. It looks as though after a very short anœstrum following the summer gestation, the pro-œstrous cycle again commences ending in copulation of the females in the cold weather. At about this time of the year the temperature falls rapidly and these animals seem to enter on a period of winter hibernation, for they are less scarce and can be procured only with difficulty. According to Marshall (1922), the sperms are received in the fallopian tube during the period of hibernation where they are retained for some time in a state of suspended animation and when the bats emerge into activity, fertilisation occurs without further copulation.

THE NUMBER AND DISPOSITION OF EMBRYOS.

There are always two young ones born. Marshall (1922) mentions in his " Physiology of Reproduction " (page 624) that at a time only one is born. This author simply followed the previous workers like van Beneden (1888*a*), M. Duval (1895) and Nolf (1896). Nolf (1896) working on *Vespertilio murinus* remarks on page 578 thus : " Le blastocyste arrive dans l'uterus se fixe tojours, comme l'ont deja observe Ercolani et van Beneden dans le corne droite." Further Duval (1895) in his account of the cheiroptera mentions on page 149 : "Nous dirons d'abord que la gestation à tojours, sans exception, lieu a droite." In the light of these facts there seems to be a predilection exhibited by the blastocyst to choose always the right cornu. However, Vogt* mentions that in a few cases of 'noctules' there were two embryos. In all the forms that I have examined I have noticed the occurrence of two young ones. Therefore two seems to be the rule in Vesperugo, while one is an exception. In order to substantiate this point I have closely examined the sections of the ovary and at least six to seven ova are seen to undergo the first maturation division in the ovary. It is just possible that two may be fertilised to undergo the further developmental phases. The most recent author, Sansom (1932) who describes the early stages in the development of the South American bat, Molossus does not refer to the occurrence of more than one blastocyst in those forms. Possibly the fact of the occurrence of two embryos in the uterus (one in the right and one in the left side of the uterus) is not only specific to *V. leisleri*, but to the genus as a whole, since two embryos are discovered in many other species of Vesperugo.†

Again, as regards the disposition of the blastocyst in the uterus there is a great deal of variation. The future site of the placenta entirely depends on the polarity of the embryonal cells of the blastocyst. According to early authors such as van Beneden (1888*a*), Nolf (1896) and Duval (1895) it is obvious that the embryonal pole is always orientated towards the antimesometrium, which is the seat of the future placenta. In all these cases, therefore, the placenta is antimesometrial. Peculiarly, however, Sansom (1932) describes a few cases of Molossus where the embryonal disc is at right angles to the mesometrium. In later stages he points out that it becomes antimesometrial and it may be predicted that in these bats, the placenta is ultimately antimesometrial. I have secured five very early stages, two of them exactly corresponding to two of Sansom's cases (see Sansom's photomicrographs, Plates 1 and 2, Figs. 2—7, *Proc. Zool. Soc. Lond.*, Part 1, p. 113, 1932). The stages that I have secured may briefly be noted here. The first one is an early blastocyst with the embryonic knob closely attached to the modified dermis ; in the second there is a depression in the embryonal mass ; whilst in the third the embryonal mass has developed a future amniotic cavity ; in the fourth the amniotic cavity opens to the exterior and the last, where the embryonal disc is flat and is proliferating mesoderm. In all these forms I notice that the embryonic mass of cells is always orientated towards the antimesometrium and therefore I conclude that the phenomenon described by Sansom does not occur in this form. Having in view this interesting observation, we notice that a point of great phyletic significance arises in connection with the seat of the placenta of the megacheiroptera. Göhre (1892) describes that the placenta in Pteropus is mesometrial. Then, naturally a question may be asked as to which is older,—the mesometrial or the antimesometrial placenta ? This question must remain unanswered, for, unless we study all the forms, a definite conclusion cannot be arrived at. A tentative opinion may be hazarded. Possibly the original site of placental attachment was mesometrial, which (in all its primitiveness ?) is preserved in the megacheiroptera, and the more recent is the antimesometrial. This view is not hypothetical but is supported by evidence. The clue to this interesting subject is Sansom's discovery where, possibly, the embryos being originally mesometrially directed are gradually shifting their orientation and are becoming antimesometrial. It is generally accepted that the side on which the embryonic rudiment is present, is also the side on which the placenta is formed. In the light of this generalisation, the placenta, therefore, in the recent bats is shifted to the antimesometrial side. This question of the genealogy of the cheiroptera could only be settled provided embryological evidences are supported by comparative anatomy and palæontology.

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* See for Vogt, Duval, 1895, *Journ. Anat. et Phy.*, Vol. 31, p. 150.

† See *Fauna of British India*, Blanford, " Mammalia ", 1888-91.

PREGNANT UTERUS.

A. (i) *Blastocyst* (*a*). By the long axis 1·4 mm. By the short axis 0·017 mm.—This is the earliest stage in the series of blastocysts and is characterised by the following features.

The embryonic mass of cells is closely adpressed to the uterine dermis, and the uterine epithelium has disappeared from this region. The trophoblast, having columnar cells in the region of the placentary annulus, is continuous with the epiblastic mass and has not yet reached the mesometrial pole. Thus, in this part of the uterus the uterine epithelium is seen in certain regions as a distinct layer of cells while in other parts it appears as a degenerate mass of cells. As soon as the trophoblast comes in contact with the uterine wall, the uterine epithelium is lost, and I am unable, at present, to describe this process of the disappearance of the uterine epithelium since my slides do not show it very clearly.

The dermis is showing signs of modification ; it is becoming more vascular and the cells are seen in active mitotic division. Fig. 1 is drawn to represent the entire blastocyst *in situ*, and Fig. 2 is drawn under higher magnification to show the modifications in the dermis noted above.

A. (ii) *Blastocyst* (*b*). By long axis 0.11 mm. By short axis 0.07 mm.—(See Fig. 3.)—Herein is recorded a very interesting case of an early stage of pregnancy.

The embryo is a round mass of cells with a small depression in the middle and the edges of this mass are in continuity with a layer which will be presently described. This layer which is thin and composed of flattened cells is internal to the trophoblast whose purpose I am unable to describe at present. The yolksac endoderm layer is closely apposed to this thin layer internally. The mesoderm is not yet formed. On the other hand, the trophoblast has progressed considerably. The plasmodiblast has enveloped a series of vessels and further a large number of lacunæ are to be seen in the same layer. The paraplacentary layer which will be described later has already made its appearance here. It is rather difficult to correlate this phenomenon of unequal growth, on the one hand the early stage of the embryo and the advanced condition of the placentation on the other. Possibly this is a case of abnormality.

A. (iii) *Blastocyst* (*c*). By long axis 0.07 mm. By short axis 0.16 mm.—(See Figs. 4 and 5.)—The embryo has advanced by one step ; a cavity has made its appearance in the embryonal mass, which is the future amniotic cavity. The cells roofing this cavity are smaller than those that form the floor of it. The trophoblast is separate from the embryonic disc.

It is a matter of common knowledge that the internal layers of the uterus undergo certain preliminary changes for the reception and the subsequent implantation of the blastocyst.

The blastocyst under examination has been described above. It is implanted centrally on the antimesometrial side. In order to ensure this implantation certain changes take place in the dermis, connective tissue and the blood-vessels.

Before proceeding to narrate the modifications, one very important point ought to be mentioned. The uterine epithelium has disappeared. Now, this disappearance has been attributed by previous workers to the following causes. On account of the prolific multiplication of the cells of the dermis the uterus increases in size and the uterine epithelium does not keep pace with this augmentation. Consequently the cells become first thin and then flat and pavementous. Soon, these cells break away leaving exposed to the trophoblast the already modified superficial dermis. It would not be out of place here to quote M. Duval's sentences (page 148, 1895) in regard to the fate of the uterine epithelium. " L'epithelium de la muquesse uterine est primitivement forme de cellules clylindriques a cils vibratiles. Des que l'oeuf arrive dans l'uterus, cet epithelium perd ses cils vibratiles, d'abord dans la region superieure, puis dans la region inferieure ; puis, presque aussitot les cellules epitheliales de la region superieure s'atrophient en une couche mince, homogene, semee de noyaux ; enfin, losque l'oeuf contracte ses premiers adherences, c'est son cette region superieure, dont l'epithelium n'est plus represente que par quelque rares noyaux plats semes dans un lisere extremement mince."

This epithelial degeneration described above leads immediately to the attachment of the trophoblast with the uterine dermis.

The embryonic rudiment is turned towards the antimesometrial border as already pointed out and therefore the uterus could be studied in two parts ; the embryonal oı antimesometrial side and the nonembryonal or mesometrial side. This character seems to be manifest in all the microcheiroptera. The amniotic cavity is roofed only by a thin layer of epiblastic cells. Further, the trophoblast has differentiated itself into a proximal cytoblast and distal plasmodiblast. The former exhibits cubical cells in which active mitosis could be observed. The plasmodiblast, which is adjacent to the modified dermis, has not yet engulfed the maternal capillaries. Into this plasmodiblast the cellular prolongations or buds of the cytoblast could also be seen entering.

The trophoblast in the nonplacentary region is thin and flat and is lined internally by a similar yolksac endoderm layer.

The next part to be considered during this period of gestation is the dermis. In the superficial dermis active multiplication of cells is seen ; the blood-vessels have invaded this layer profusely. In certain places the uterine capillaries are in direct contact with the trophoblast and moreover on either side of such capillaries the tongue-like projections of the plasmodial part of the trophoblast are also observable. This layer (the superficial dermis) plays an important part in the placental physiology and is called by Nolf (1896) the 'paraplacentary layer', and is comparable with the decidual layer of the Rodent placentation.

I shall now proceed to consider the blood vessels. It has already been remarked that the arterial capillaries have distributed themselves near the plasmodiblast. Before their location in such close proximity with the trophoblast they, along with the venous vessels, divide into a rich network of capillaries. This division is more obvious in the deeper dermis since the surrounding tissue is very little.

The deeper dermis (comparable with the subdecidual layer of rodent placen^ta) which must next engage our attention comprehends a large set of veins, the cells of which are in a state of division. Some parts of the vein are extremely thick due to the greater number of cells forming the wall. Some of the cells seem to undergo a process of necrosis and the nuclei in various shapes—some U-shaped and others definitely segmented—are seen to be thrown into the cavity of the vein. The cellular hypertrophy can be very well studied at this stage. Further the cells of the dermis itself are modified. They are flattened with sparsely distributed spindle-shaped nuclei and also assume a fibrous aspect.

The glandular crêtes as described by Nolf (1896) for Vespertilio are not to be seen in Vesperugo. The disposition of the glands is entirely different. The long axis of the gland is parallel with the long axis of the embryo, while it is the opposite in Vespertilio. The glandular cells are cubical and the cavities of the gland contain a secretion (?) which is stained red with eosin.

A. (iv) *Blastocyst* (*d*). By long axis 0.28 mm. By short axis 0.12 mm.—(See Figs. 6 and 7.)—As in the previous stage (blastocyst *c*) the embryonic rudiment is towards the antimesometrial side and has undergone one definite change. The amniotic cavity which in the previous stage was a closed vesicle is now open towards the trophoblast by the rupture of the covering epiblast cells. The trophoblast which can be distinguished under high power as an external plasmodiblast and an internal cytoblast in the region of the placentary annulus is represented only as the plasmodiblast over the vault of the embryo. In other words the amniotic cavity (the ectotrophoblastic cavity) in this region is directly in contact with the plasmodiblast.

The trophoblast in the nonplacentary zone is as in the previous stage.

A word or two must be said about the amnion formation in these forms. The formation of the amnion is interpreted in a variety of ways and it looks as though it seems to vary with reference to the animal examined. The early workers like van Beneden and Julin (1895), Nolf (1896) and Duval (1895) examined *Rhinolophus ferrum equinum* and *Vespertilio murinus.* Duval (1895) describes the formation of amnion in Vespertilio as follows: " After the roof of the amniotic cavity has been separated off in small fragments from the solid floor the true amnion is eventually formed by the fusion of the free edges of the true epiblastic mass. " Following the observations of Duval, Assheton (1899) narrates how the trophoblastic layer over the embryonic cell mass is lost and the amnion formation is brought about by the subsequent fusion of the epiblastic folds and not by the trophoblast. Da Costa (1920) working on *Miniopterus schreibersii* comes to a similar conclusion in pointing out that the amnion arises as a closed cavity which later disappears and is replaced by a tropho-ectoblastic space and subsequently, the amnion is formed by folds. Hill and Tribe (1924) in a paper embodying an account of the early development of the cat (*Felis domestica*) review the literature on the subject of amnion formation in mammals in general. They point out that the description given for *Vesperugo noctula* by O. van der Stricht (1899, 1911) is an exception; "Since," they say "here the ecto-trophoblastic cavity only appears after the embryonal ectoderm has spread out below the covering trophoblast in the form of an epithelial layer, but in an earlier stage, when the embryonal ectoderm is in process of differentiation, van der Stricht states that there are present, between the latter and the already attached placental trophoblast, 'souvent des fentes, des espaces irréguliers, en quelque sorte virtuels, autour desquels sont sériées les cellules épithéliales de l'epiblaste embryonnaire' (1911, page 7). These spaces disappear as the embryonal cetoderm spreads out in close contact with the placental trophoblast, but there can be little doubt they represent the cetotrophoblastic cavity which here becomes temporarily obliterated owing to some exceptional condition of pressure inside the blastocyst of this particular species." In the two early stages that I have described the primitive amniotic cavity is fully established and it is not possible to say if chinklike spaces in the embryonic ectoderm united together to form the said cavity. But following Levi

(1922) the origin of the primitive amniotic cavity depends upon the form and disposition of the inner cell-mass at different intervals of growth. Judging by the precise nature of the contour of the cavity it may be said that a re-arrangement of cells in the embryonic mass gave rise to the spacious amniotic cavity. In sections passing through the middle of the embryonic ectoderm the cavity referred to is open towards the covering trophoblast (which is in the form of a plasmodiblast). This ecto-trophoblastic space is noticed to disappear in the case of *V. noctula.* In *V. leisleri*, on the other hand, it persists and is incorporated with the amniotic cavity finally when the embryonic ectoderm forms the amnion by folds.

The cells of the dermis are in active division, and are more intensely stainable than in the previous stage.

The yolksac endoderm is closely applied to the cytoblast.

The glands at the mesometrial pole show increased activity, than in the previous stage.

A. (v) *Blastocyst* (*e*). By the long axis 0.62 mm. By the short axis 0.07 mm.—(See Figs. 8 and 9.)—The gap between the last and this stage is very wide. The embryonic rudiment is in the form of a thin plate with a primitive streak in the middle. On either side of the streak the formation of mesoderm is obvious. This mesoderm is showing signs of spreading over the yolksac. The future amniotic cavity is large, and this stage corresponds with or is slightly older than the one recorded by Sansom (1932) in Figs. 7 and 8, Pl. II. The bend of the shield ectoderm towards the placental trophoblast in my slides is clear to form the amnion. The layer of covering trophoblast over the primitive amniotic cavity is extremely thin and in this and in all other cases 'the true amniotic cavity is later established by the extension of the ectoderm from the margins of the embryonal plate, beneath the covering trophoblast, followed by the extension of the mesoderm and the extra-embryonal cœlom in between the latter and the ectoderm.' In the next stages that I have described (B and C) the amnion is fully formed.

The cytoblast is very clear and the plasmodiblast has not yet engulfed the other vessels which are situated close to it.

The dermis is modified considerably ; the cells are multiplying and the paraplacentary layer has increased in size.

B. & C. *Allantoic rudiment and the rudiment bent towards the trophoblast.*—These two stages may be considered together. In the former (Figs. 10 and 10*a*) the allantois has just made its appearance and in the latter (Fig. 14) it shows a definite bend towards the trophoblast.

The allantois which is only a small endodermal diverticulum surrounded by a large mass of splanchnic mesoderm makes its appearance from the posterior end of the mesenteron of the embryo in both stages. Besides, this allantoic rudiment is highly vascular.

The trophoblast in the region of the placentary annulus is seen as an external plasmodiblast and internal cytoblast layers as in previous stages. The cytoblast is very prominent and the columnar cells with equally large highly stainable nuclei are noticed in the form of buds entering into the plasmodiblast layer. In between these two layers Duval (1895) interposes a third layer the ' transition layer '. In my preparations no such intermediate layer can be made out. In the mesometrial side the trophoblast layer is thin with flattened nuclei (see Fig. 11).

It has already been remarked that in the region of the formation of the placenta, the uterine dermis is so reorganised as to constitute a very important layer physiologically different from the other parts, called the paraplacentary layer which recalls the decidual layer of the other haemochoreal types of placenta (see Fig. 11*a*). It is possible to distinguish two distinct regions in the paraplacentary layer ; a more compact superficial layer which is in contact with the plasmodiblast and a deeper spongy one. This superficial layer is thin and the cells are oval having similarly shaped or roundish nuclei. Many of these nuclei are seen to possess two nucleoli. The deeper paraplacentary layer whose cells are in close contact with the dermis (sub-decidual layer) is seen to ingest constantly nutritive material from the latter layer ; in other words a large number of cells from the dermis are necrotised and are absorbed into the paraplacentary layer. Possibly this necrotised decidua forms an important constituent of the embryotrophe being the chief source of food supply for the developing embryo in the very early stages of gestation. It is therefore unnecessary to restate that this paraplacentary layer crammed with degenerate cells recalls the deciduofract layer in Erinaceus (Hubrecht, 1889*a*) and the trophospongeal layer of the Carnivora.

The true or the deeper paraplacentary layer is in the form of a network, the nuclei occupying the corners of this network. The entire layer therefore is thin and spongy. In Fig. 12 on the two lateral sides of the paraplacentary layer the network is crammed with a coagulum.

Towards the muscularis is the dermis layer or the subdecidual layer, where a large number of blood-vessels are present. The uterine arteries and veins on entering the paraplacentary layer ramify. It is extremely difficult to distinguish the artery from vein, since the walls of both are hypertrophied. The arteries running perpendicularly to the surface of the plasmodium are the first to be engulfed by the latter. In fact at this stage a large number of arteries have been surrounded by the active plasmodiblast and further many more being in close contact with the plasmodium will be enveloped. The veins are not yet surrounded by the syncytial layer. These vessels are situated at the base of the augmenting plasmodial layer in close proximity with the superficial dermis or the paraplacentary layer.

The dermis is thick and contains a large number of blood-vessels. This layer is continuous both in the mesometrial and also in the antimesometrial sides. On the mesometrial side where there are a large number of glands which are transversely situated the trophoblast is in apposition with the openings of some of these glands. In my preparations it is noticed that the glands contain a secretion which is stained red by eosin. Except for this no cellular detritus as observed in similar preparations in the paraplacentary layer could be seen in the glandular region. In close contact with this secretion is noticed the trophoblast and the yolksac endoderm, both of which show flattened cells in this region.

The veins and arteries of this region (on the antimesometrial side) show a marked hypertrophy. The cells of the walls of the veins are seen to undergo mitotic division. Further projecting into the lumen of the vein can be observed small blunt processes from the wall of the veins. I am not able to trace the exact nature of these blunt processes. Found floating in the blood one may notice a large number of leucocytes with variously shaped nuclei. These leucocytes which are found floating both in the arterial and venous capillaries are the degenerate products of the cells found in the walls of the blood vessels (see Fig. 12*a*). These should not however be mistaken for the normal component of the blood.

The allantois has made its appearance as a small projection from the posterior portion of the mesenteron. This projection is composed of a rich plexus of vessels in the allantoic splanchnopleure and a small endodermal diverticulum. This precocious appearance of the allantoic rudiment with a small endodermal projection into it need not excite surprise, for a similar phenomenon has been noticed in many other mammals.

The yolksac which has been described as occupying the entire cavity of the blastocyst in the two previous stages, has assumed a functional activity in this stage. It is noticed that an active circulation is set up in the splanchnopleure of the yolksac by a system of vessels and the sinus terminalis is also discernible. In a region where the embryo is absent from the sections, the highly vascular yolksac is in close contact both mesometrially and antimesometrially with the trophoblast. Thus it appears that the embryo at this stage actually lies in a hallowed cavity of the yolksac.

The great vascularisation of the yolksac in the antimesometrial pole and its absence in the mesometrial pole can be easily explained. Long before the allantois establishes connection with the trophoblast the yolksac endoderm with its rich supply of blood-vessels will have formed a type of yolksac placenta, aiding the fœtus in its growth. At the mesometrial side (see Fig. 13) the yolksac endoderm being devoid of a mesodermal coat comes in direct contact with the glandular region. Phagocytosis may not be uncommon when a situation like this is present.

Fig. 13*a* is a magnified view of the edge of the placenta at this stage. The termination of the plasmodiblast layer and the continuation of the cytoblast layer on to the mesometrial pole is very clear. This extraplacental trophoblast in the final stages of pregnancy bends over the plasmodiblast into the dermis and forms the chorian læve (see Fig. 23*a*).

Stage D. *Attachment shown by the Allantois.*—(See Figs. 14, 15 and 15*a*.)—It was pointed out that in stage C the allantoic rudiment shew signs of a definite bend towards the trophoblast. In this stage it has grown and attached itself to the trophoblast, but it has not yet spread itself.

No further changes in the trophoblast from the previous stage are observable.

The yolksac has considerably receded but the sinus terminalis is in contact with the edge of the placenta.

The structure of the placenta is shown in Fig. 15*a*. There is not much difference between this stage and the previous one except, however, that the plasmodiblast is excavated into a larger number of lacunæ; the lacunæ being formed by the disappearance and subsequent absorption of the capillaries. All these lacunæ are flooded with maternal blood. The cytoblast is noticed to send in prominent projections into the plasmodiblast.

The allantois is slowly growing and the part of the trophoblast in immediate vicinity is all covered by the allantoic mesoderm and is gradually progressing on the left side (Fig. 16).

Fig. 16*a* is a tangential sectional view of a placenta, a little more advanced than the stage represented in Fig. 16. The plasmodiblast is like a large sheet and in it could be observed parts of allantoic mesodermal portions. The cytoblastic lining of the lacunæ is very characteristic of this stage.

Stage E. *The Placenta (Pregnant Uterus 5 mm.).*—The allantois has spread itself on the internal aspect of the placentary annulus. Villi-like outgrowths of the allantois have grown into the pocket-like portions of the cytotrophoblast. All the same the yolksac mesoderm is in close apposition with the terminal part of the placentary annulus; the allantoic placenta has not yet replaced the yolksac placenta. A small endodermal vesicle in the allantois can be seen.

The amnion is attached to the allantoic mesoderm in the region of the placenta.

The trophoblast is very thick; this augmentation in size is due to the enveloping of arterial capillaries which are towards the embryo and the venous ones which are situated more internally (see Fig. 17). The cytoblast is clearly visible, composed of cubical cells and large cytoblastic projections are seen entering the plasmodiblast. Between any two projections of the cytoblast is seen the allantoic mesoderm with capillaries projecting. Further, the plasmodiblast has prominent areas of clearly demarcated cells, which are the islands of cytoblast. In certain regions it is noticed that the plasmodiblast has apparently enveloped portions of the allantois; in these regions it is clearly seen that the cytoblast cells form an internal lining for the plasmodiblast, incidentally surrounding the allantoic mesodermal villus.

The paraplacentary layer is thick; as before two layers can be easily made out. The deeper true paraplacentary layer is studded with the detrital matter from the dermis, and the superficial one is in contact with the growing placenta. Some of the venous vessels present in this layer are being slowly surrounded by the progressive plasmodiblast. In addition to the occurrence of decidual cells in the paraplacentary network in the previous and this stage it is noticed that a large amount of secretion also occurs. These are globules of various sizes found imbedded in the paraplacentary network. These are not affected by eosin and are coloured dark grey. Further, in the same layer nuclei in various stages of transformation could be seen. Some are large and are imbedded in the corners of the network. Others are small, usually associated with a large and highly stainable body.

The dermis is very active; many cells undergoing mitosis are seen. Some of the cells have assumed a lozenge shape. The veins and arteries possess thick walls on account of the hypertrophy of cells. In the lumen the usual leucocytes described in the previous stages are also seen (Fig. 12*a*).

Fig. 17*a* represents a sectional view of the placenta at the 5 mm. stage. The plasmodiblast which was described as sheet-like in the previous stage is becoming lamellar and in between the lamellæ are the large allantoic portions. The engulfed arteries and the invading allantoic splanchnopleure are seen very well.

In Fig. 18 the proximal wall of the yolksac is shown. The thick splanchnopleure covering the yolksac and possessing a large number of vessels, is possibly functionally active at this period of gestation. The endodermal cells are columnar and free from granules. The clear nature of these cells or the vacuoles in them is due to the dissolution of granules by fixatives like Bouin, etc., and I have not yet had opportunities to study osmic material to examine the lipoid contents of these cells.

Stage E. (*Pregnant Uterus 7 mm.*).—(See Figs. 19 and 20.) The placenta has increased in size and is thicker than in the last. The plasmodiblast in certain regions shows the lamellæ clearly. The free extremity of the lamella is towards the fœtus and always encloses an arterial capillary. In between any two such lamellæ, each enclosing an arterial capillary, a large amount of allantoic mesoderm may be seen. In other parts the plasmodiblast is excessively thick enclosing several islands of splanchnic mesoderm and at the free terminus of such a plasmodiblast (towards the fœtus) is a large arterial bay. The cytoblast could only be recognised by the even occurrence of the flattened nuclei in this stage.

The paraplacentary layer shows considerable advancement. The phagocytosis has advanced by leaps. The culmination of this interesting phenomenon of phagocytosis is noticed in the occurrence of large spaces in the deeper paraplacentary layer. In fact a series of steps can be traced in the formation of these spaces. The cellular contents from the dermis layer after undergoing degeneration are cast into the deeper paraplacentary layer, which is spongy. In turn the paraplacentary layer undergoes an important histolytic change. The remaining cellular outlines are lost, and thus large spaces are left behind. Such spaces are not noticed in the earlier stages of gestation.

The muscular layer is very prominent and occupies a greater part of the uterine wall.

The amniotic mesoderm is getting united with the allantoic portions as in the previous stage.

The yolksac is getting diminished in size. It is observed as a small vesicle on the mesometrial side.

Stage E. (*Pregnant Uterus 9 mm.*).—(See Figs. 21, 21*a* to 21*c*). The placenta is thick. The vesicular allantois has extended into the plasmodiblast considerably. Between any two allantoic portions a large mass of plasmodiblast could be seen. In this plasmodiblast layer a number of lacunæ filled with maternal blood as in the previous stage is also found. The plasmodium having engulfed the paraplacentary veins is slowly progressing towards the interior of the paraplacentary layer. Now, the placenta can be described as follows. Internally towards the fœtus there are large arterial sinuses which are the vessels enveloped at first by the plasmodiblast and internally towards the paraplacentary layer there are the large venous sinuses surrounded by the plasmodiblast finally. In between the arteries and veins a set of highly branched capillaries can be seen. All these three systems—the arterial sinuses, the capillaries and the venous sinuses—are to be distinguished in the plasmodiblast.

While the plasmodium is in the form of lamellæ in the inner region it is a flat region in the external part (towards the muscularis). Thus in a perpendicular section it is seen as a network of irregular nature. Naturally we are led to believe that these plasmodial bays are independent of one another. But that it is not true becomes manifest when one examines the transverse or longitudinal sections of the uterus. It is definitely seen that the plasmodium is a continuous structure. Further in the perpendicular sections the allantoic mesoderm forms a core for the cytoblast and the plasmodiblast. In the next stage this appearance is lost (see Fig. 21*a*).

The arterial vessels are seen possessing a perivascular sheath. The veins are devoid of this, and the cells in the walls of the vessel are still dividing. In certain regions the endothelium is particularly thick.

The dermis is thick in some parts and thin in others. The fibrous nature is only seen in certain parts. The spaces referred to in the previous stage are also seen in this stage. The dermis is no more showing cellular divisions.

The paraplacentary layer is full of disintegrated cellular matter derived from the dermis. The detritus consists of broken down cells, the protoplasm of which is stained by eosin and the nuclei by hæmatoxyline. This cellular detritus is sometimes observed to be in close proximity with the plasmodiblast. The meshwork of this paraplacentary layer in which detrital matter is found persists in certain regions while in others it breaks down to give rise to large spaces. In the meshwork the spaces are all elongated and the long axis of these spaces are parallel with the long axis of the uterus. The nuclei studded in the fibres of the meshwork are highly chromatic, oblong and carry a nucleolus.

Fig. 21*b* is a tangential section of the placenta at this stage. The plasmodiblast is full of lacunæ and is interspersed with the allantoic mesoblast. Further, a very important change has taken place. The cytoblastic lining for the plasmodial bays has disappeared, so much so the allantoic mesoderm is separated from the maternal capillaries by the thin plasmodiblast.

The mesometrial yolksac and the trophoblast are shown in Fig. 21*c*. The yolksac has almost lost its cavity and the proximal wall has come in close contact with the mesometrial epiblast. I have already remarked that I was not able to make osmic preparations and therefore I shall not venture to remark about physiological importance of the yolksac. For the same reason I am not able to explain the symplasma (?) formed in the uterine wall on the non-embryonic side. Possibly this is due to the proximity of the trophoblast with the uterine wall. Needless to point out that the uterine epithelium is lost.

Stage E. (*Pregnant Uterus* 12 *mm.*).—(See Figs. 22 and 22*a*.) This stage is marked by the great development of the placenta and the attenuation of the cavity of the yolksac and an almost complete disappearance of the uterine glandular enlargements in the mesometrial side.

The plasmodiblast has enveloped a major portion of the paraplacentary layer and therefore the uterine part looks thin. The plasmodial pillars in almost all the regions have united together thus encompassing the allantoic part. The arterial capillaries and the elongated venous vessels are all seen. The cytoblast is no more observable.

The paraplacentary layer is minimised in size, and still the deeper part has a considerable amount of the products of degeneration.

The mesometrial wall where the symplasma was observed in the previous stage (see Fig. 21*c*) has considerably increased now. The proliferative trophoblast has established intimate connections with the dermis (see Fig. 22*a*).

In close contact with the trophoblast the yolksac wall is also noticed. The blood circulating in the yolksac mesoderm shows corpuscles devoid of nuclei.

Stage E. (*The fully grown Placenta*).—(See Figs. 23, 23*a* to 23*c*.) The uterus containing the two young ones is sectioned and it is observed that the maximal edification of the placenta is accomplished. The blood is circulating in the sanguimaternal lacunæ. A well-developed chorion læve is also present.

The placenta is of the hæmochorial type. The maternal blood is circulating in thin plasmodial lacunæ and any two such lacunæ are separated by a thin allantoic mesoderm so much so the gaseous and nutritive exchanges can take place easily. The absence of cytoblast has already been noted in the previous stage. The large arterial sinuses and the venous ones are present in their respective places (see Fig. 23).

The paraplacentary layer is thin. In certain regions this layer is incomplete and the placenta is directly in contact with the dermis. The paraplacentary layer shows no more of the detritus. As previously stated the cells of this layer are perpendicularly disposed.

The dermis cells are now normal. Here and there few cells may be seen undergoing disintegration. The lateral margins of the uterus are thin.

A very important feature of this stage of placentation is the presence of chorion læve (Fig. 23*a*). This chorion læve is merely the extension of the extraplacental trophoblast into the uterine dermis which is subjacent to the placenta. The trophoblast as soon as it leaves the placenta, ascends and eats its way into the dermis. If we follow the chorion læve from the side of the uterine wall, it is noticed that the trophoblast is closely attached to the dermis. Following we meet the other layer of the trophoblast forming the external boundary of the edge of the placenta. Internal to this layer of trophoblast, a thin layer of dermis is noticed.

Fig. 23*b* is the drawing of the extraplacental wall. It is very thick, a condition already foreshadowed in the previous stage. A definite thick uterine symplasma is formed and the cells of the trophoblast in certain regions are indistinguishable from the cells of the dermis, except by the large size of the nuclei of the latter. The chorionic mesoderm is a conspicuous layer and bears a large number of capillaries.

The yolksac (see Fig. 23*c*) having possibly discharged its function by serving as an additional channel for securing nutrition has shrunk and become a closed vesicle with a highly vascular splanchnopleure. In certain parts the cavity of the yolksac is minimised and in other parts entirely absent recalling the condition met with in the bigger bat Pteropus. Further, the nuclei of the blood corpuscles are lost and they have assumed their normal mammalian condition already seen in the previous stage.

RÉSUMÉ

Having followed the main features of the placentation in Vesperugo, it will be noticed that it does not differ very much from that described for Vespertilio by previous workers. I was not able to secure the paper by Kemperman (1929) on the placentation of Miniopterus which happens to be the latest contribution on this subject, and therefore I am not in a position to compare the South Indian form with the foreign one.

The main features in the study of the placentation of Vesperugo are as follows :—

1. The number of embryos in *Vesperugo leisleri* is two ; and the same has been described for other species of

Vesperugo by other authors also and therefore while only one is found in Vespertilio, the genus Vesperugo gives birth to two at a time.

2. The probable origin of the primitive amniotic cavity by a rearrangement of the cells of the embryonic rudiment is hinted ; the disappearance of the primitive amniotic cavity as reported by O. van der Stricht for *V. noctula* is not observed in *Vesperugo leisleri.* In main, the formation of amnion in the South Indian form supports the descriptions of Levi.

3. The placenta is definitely antimesometrial; the descriptions of Marshall are not accurate.

4. The extraordinary proliferation of the allantoic mesoderm and the consequent attenuation of the allantoic vesicle is noted.

5. The yolksac in the final stage of gestation loses the umbalical cavity recalling the condition in the bigger bat Pteropus and persists as such till the time of delivery.

[A detailed account of the embryonic mass and the physiology of the yolksac will be attempted when I secure a sufficient number of stages to report upon.]

LIST OF ABBREVIATIONS USED IN THE PLATES.

A.	Artery.
A. c.	Amniotic cavity.
A. g.	Albuminoid globules.
Am.	Amniotic membrane.
All.	Allantois.
All. d.	Allantoic diverticulum.
All. v.	Allantoic vein.
C.	Capillary.
C. b.	Cytoblastic buds.
C. l.	Chorion læve.
C. p.	Continuation of the plasmodiblast into the cytoblast.
C. t.	Cytoblast.
D.	Dermis (Sub-decidual layer).
D. e.	Decidua to be absorbed by the paraplacentary layer leaving an intercellular space I.C.S.
D. i. s.	Dermis changing to form intercellular space.
D. p. l.	Deeper paraplacentary layer.
D. m.	Modified dermis.
E.	Embryo.
E. a.	Engulfed artery.
E. a. b.	Engulfed arterial bay.
E. e. c.	Extra embryonal cœlom.

E. m.	Embryonic mass of cells.
E. v. q.	Engulfed vein.
F. v.	Fœtal blood vessel.
G.	Glands.
G. o.	Openings of the glands.
hy. v.	Hypertrophied vein.
I. all. sp.	Projecting allantoic splanchnopleure.
I. C. S.	Intercellular spaces.
L.	Lacunæ.
Le.	Leucocytes.
M.	Mesometrium.
M. d.	Modified dermis.
Me.	Mesoderm.
M. s.	Serous and muscular part of the uterus.
M. v.	Maternal vein to be enveloped.
M. v′.	Enveloped maternal vein.
N.	Nucleus.
P. b. v.	Paraplacentary blood vessel.
Pl.	Placenta.
P. l.	Paraplacentary layer (Decidual layer).
P. s.	Primitive streak.
Ps. l.	Pseudofibrous layer.
P. t.	Plasmodiblast.
S. p. l.	Superficial paraplacentary layer.
So.	Somatopleure.
Sp.	Splanchnopleure.
S. t.	Sinus terminalis.
T.	Trophoblast. (In Fig. 12 the trophoblast is not shown.)
U. e.	Uterine epithelium.
U. e′.	Denuded uterine epithelium.
U. w.	Uterine wall.
V.	Vein.
Y. e.	Yolksac endoderm layer of yolksac.
Y. s.	Yolksac.

EXPLANATION OF FIGURES.

FIG. 1. Diagrammatic transverse section of the entire uterus with blastocyst *a*. (× 80.)

FIG. 2. Blastocyst *a*. and a part of the uterus magnified. (× 100.) Notice on the mesometrial side the persisting uterine epithelium.

FIG. 3. The placenta of the blastocyst *b*. magnified. (× 248.)

FIG. 4. Transverse section of the uterus showing the blastocyst *c*. (× 80.) Note the primitive amniotic cavity.

FIG. 5. Blastocyst *c.* and the placenta magnified. The amniotic cavity is not present in this section. (× 200.)

FIG. 6. Transverse section of the blastocyst *d.* and a part of the uterus. Inset shows a hypertrophied vein with cells showing mitotic nuclei. (× 180.)

FIG. 7. Magnified view of blastocyst *d.* (× 200.)

FIG. 8. Transverse section of the entire uterus with the blastocyst *e.* (× 100.)

FIG. 9. The embryonic part of blastocyst *e.* magnified, showing the formations of mesoderm, allantoic mesoderm and somatopleure. (× 100.)

FIG. 10. Transverse section of the uterus showing the small allantoic rudiment, the large yolksac and the sinus terminalis. (× 100.)

FIG. 10*a*. Section showing the embryo (the allantoic part), the yolksac and the trophoblast magnified. (× 100.)

FIG. 11. The placenta at the stage shown in Fig. 10. (× 200.)

FIG. 11*a*. A part of Fig. 11 magnified, showing a single hypertrophied vein. Note that the wall of the vein which is adjacent to the trophoblast is very thin. (× 248.)

FIG. 12. A part of the paraplacentary layer from Fig. 10, showing the globules. (× 100.)

FIG. 12*a*. Leucocytes of the vein. The lower ones in the figure are the normal components of the blood. (× 1500.)

FIG. 13. Transverse section of the uterus showing the horizontal disposition of the embryo and the large yolksac. (× 80.)

FIG. 13*a*. A part of the edge of the placenta magnified showing the continuation of the cytoblast into the mesometrial region and the termination of the plasmodiblast. (× 100.)

FIG. 14. Magnified view of the part of the uterus and the allantoic portion with the embryo showing the bend of the former towards the trophoblast. (× 200.)

FIG. 15. Section of the uterus showing the attachment of the allantois. Note the abbreviated endodermal projection into the splanchnopleural mesoderm. (× 80.)

FIG. 15*a*. The placenta when the allantoic rudiment has made its appearance. A large number of lacunæ have appeared in the plasmodiblast. (× 124.)

FIG. 16. Section showing the spreading of the allantois with the small allantoic diverticulum. (× 80).

FIG. 17. Placenta 5 mm. stage. (× 100.)

FIG. 17*a*. Tangential section of the placenta 5 mm. stage. (× 100.)
FIG. 18. Proximal wall of the yolksac magnified. (× 100.)
FIG. 19. Placenta 7 mm. stage. Note the growth of the allantoic mesoderm into the plasmodiblast, the engulfed veins and the system of capillaries between the arteries and veins. (× 220.)
FIG. 20. A part of the paraplacentary layer at 7 mm. stage, magnified. Note the deep and superficial layers and the intercellular spaces in the dermis. (× 124.)
FIG. 21. Diagram of the placenta and the uterus, 9 mm. stage. (× 16.)
FIG. 21*a*. The placenta magnified, 9 mm. stage. Note the lamellæ-like plasmodiblast and the insinuating allantoic splanchnopleure, the engulfed veins and the invasion of the plasmodiblast into the paraplacentary layer. (× 100.)
FIG. 21*b*. Tangential section of the placenta, 9 mm. stage. Note the absence of the cytoblastic lining. (× 100.)
FIG. 21*c*. Proximal wall of the yolksac come in contact with the trophoblast. (× 100.)
FIG. 22. Diagram of the placenta at a late stage. (× 100.)
FIG. 22*a*. Proximal wall of the yolksac come in contact with the uterine wall. (× 100.)
FIG. 23. Diagram of the placenta fully grown. (× 100.)
FIG. 23*a*. A magnified view of the chorion læve. (× 80.)
FIG. 23*b*. Mesometrial part of the uterine wall of the fully grown stage. (× 100.)
FIG. 23*c*. An entire part of the yolksac. Note the abbreviated lumen of the sac in certain places. The corpuscles are devoid of their nuclei. (× 80.)

The drawings are all made with the aid of the Camera Lucida ; Leitz objectives and eye-pieces have been used. The magnifications noted above are according to the table given by Leitz.

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PLATE I

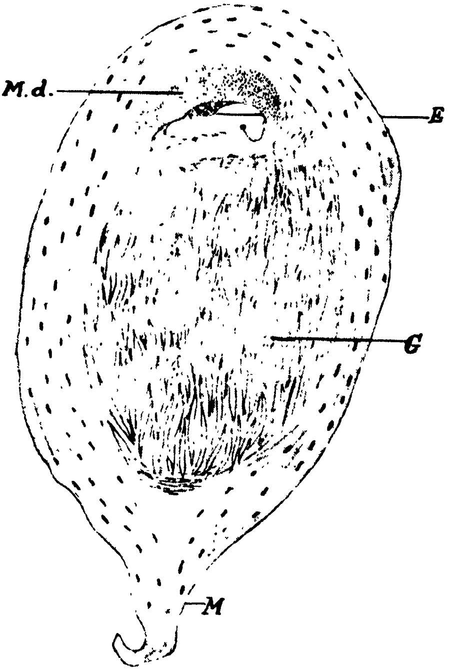


FIG. 1.

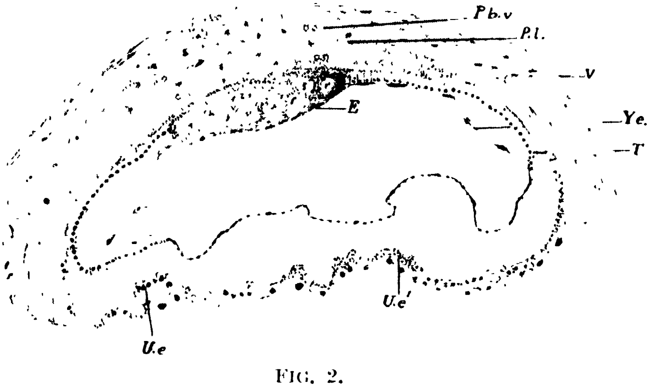


FIG. 2.

PLATE II

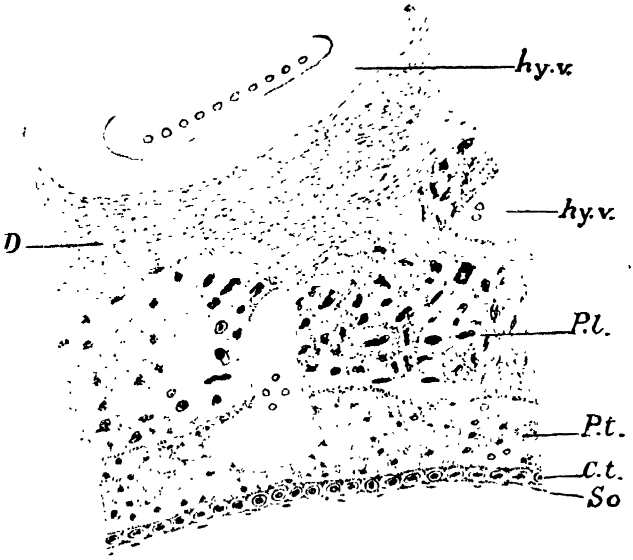


FIG. 3.

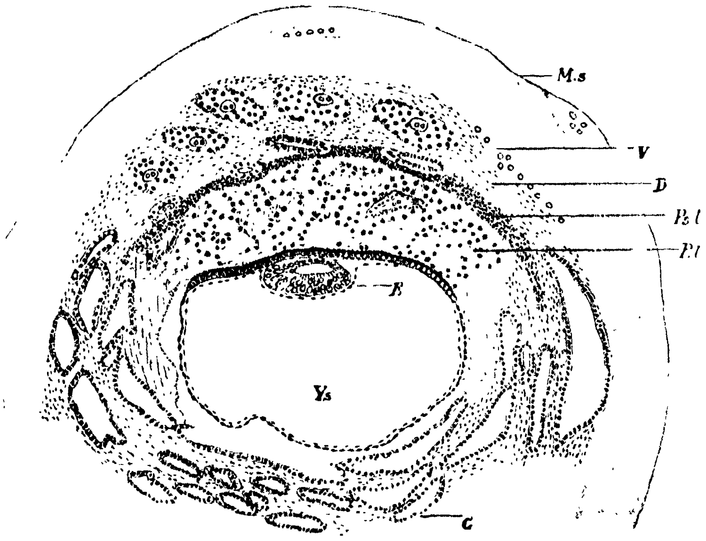


FIG. 4.

PLATE III

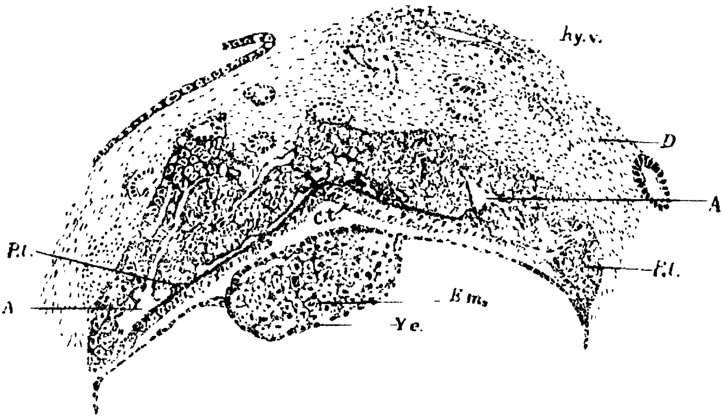


FIG. 5.

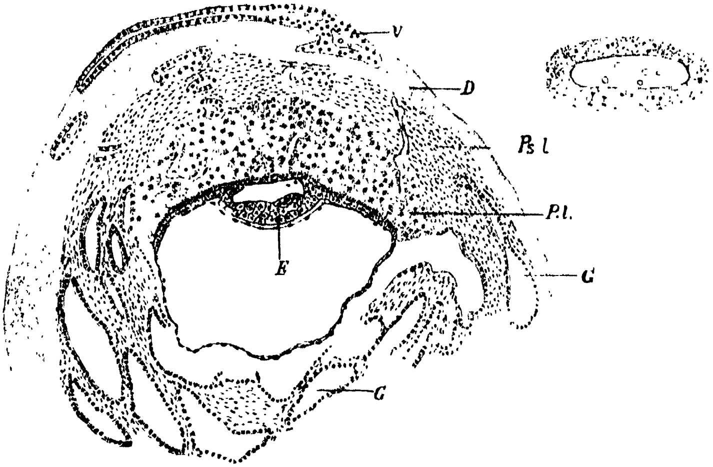


FIG. 6.

PLATE IV

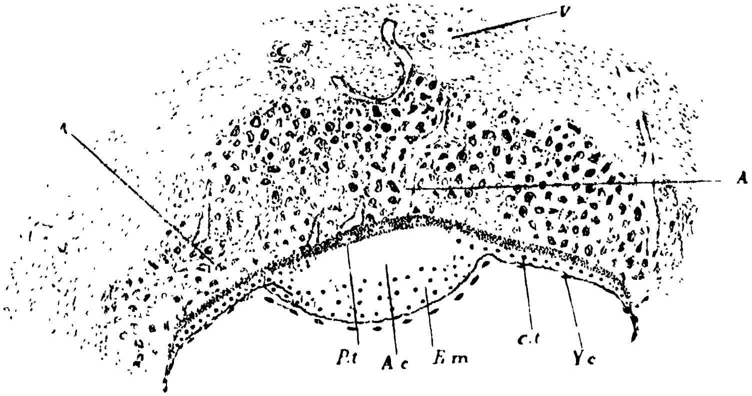


FIG. 7.

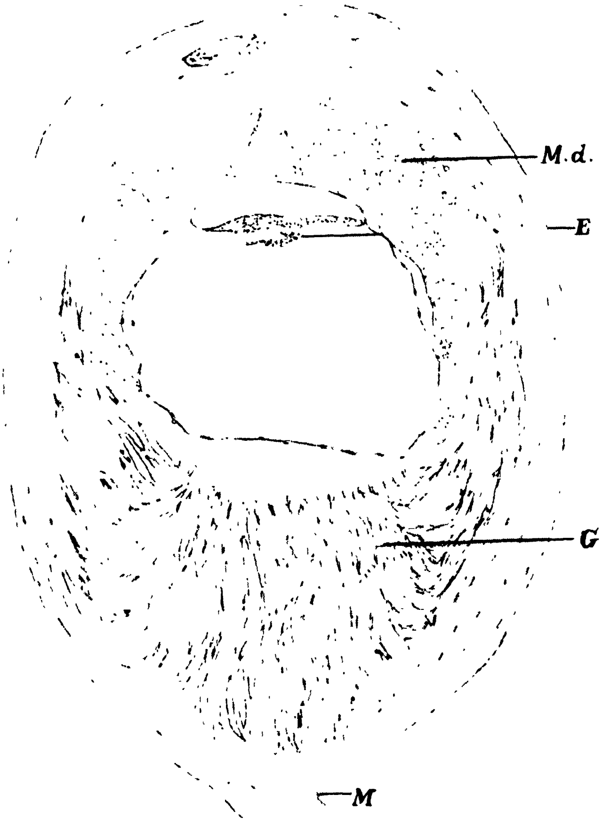


PLATE V

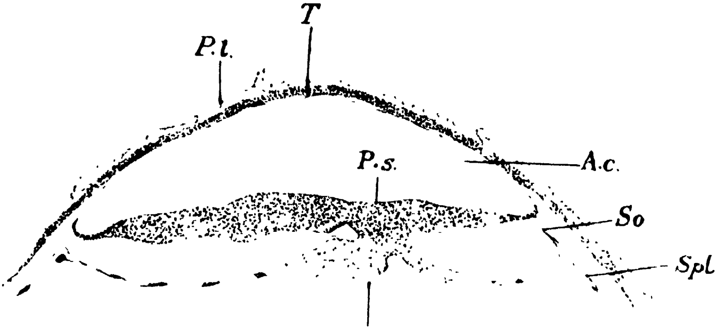


FIG. 9.

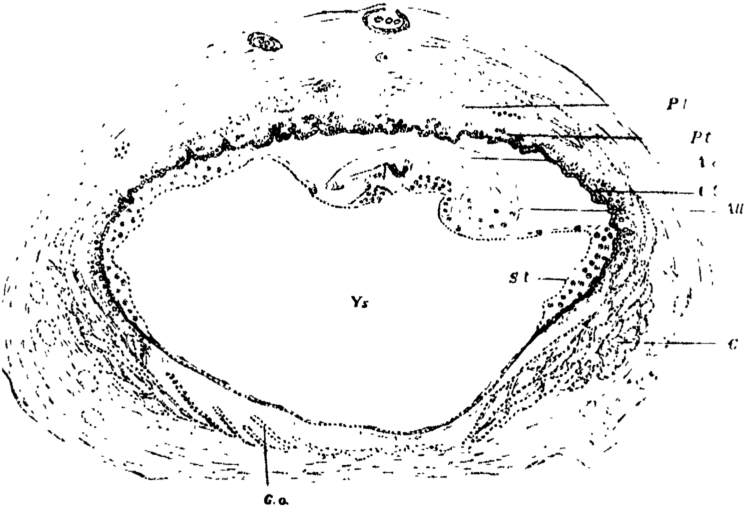


FIG. 10.

PLATE VI

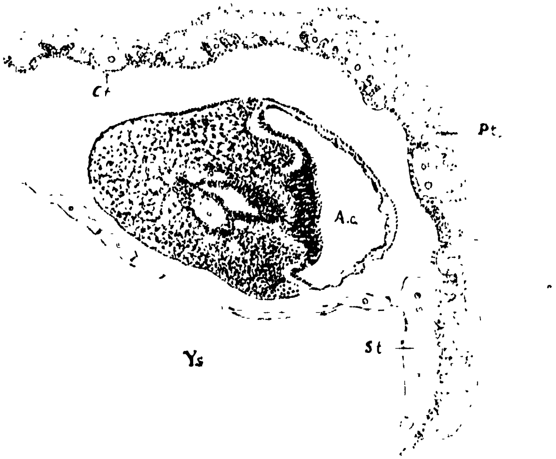


FIG. 10a.

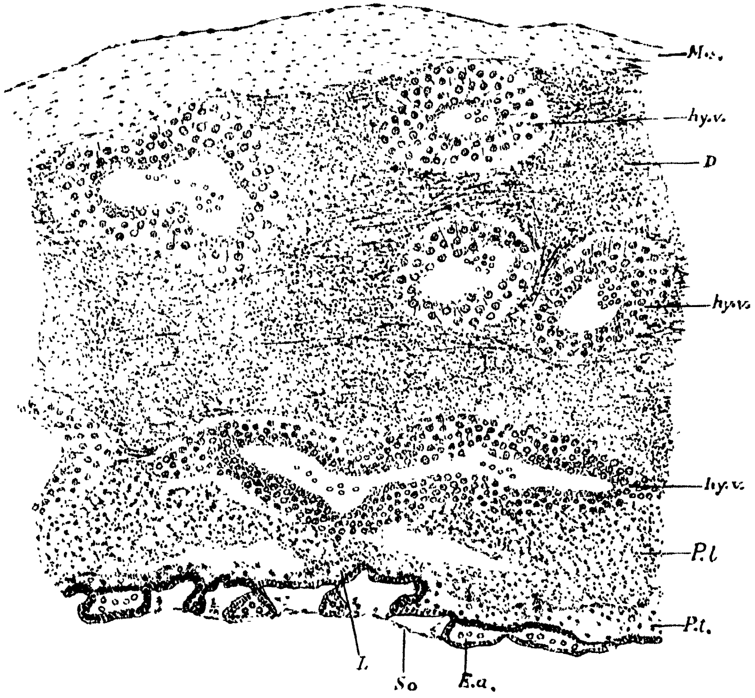


FIG. 11.

PLATE VII

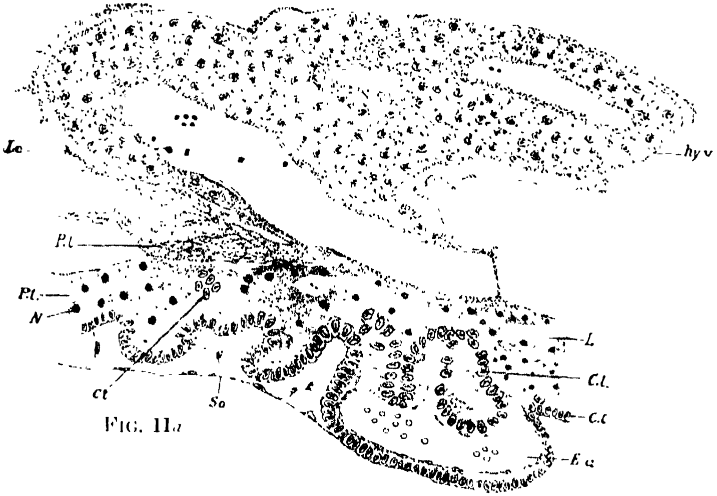
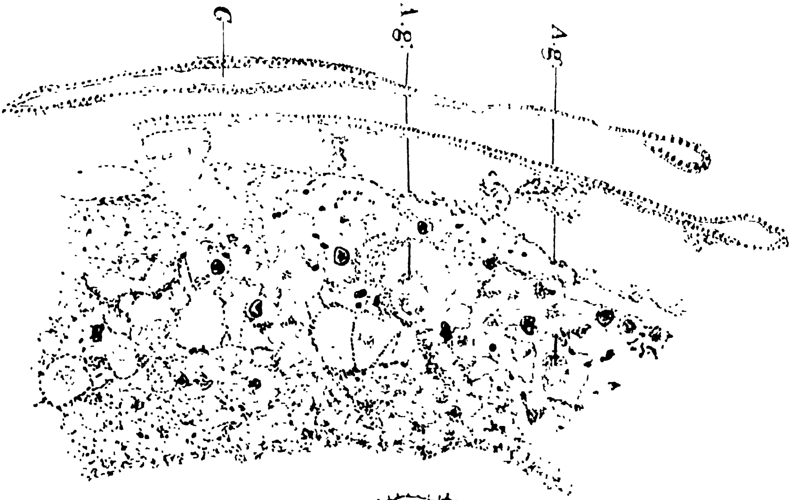


FIG. 11a



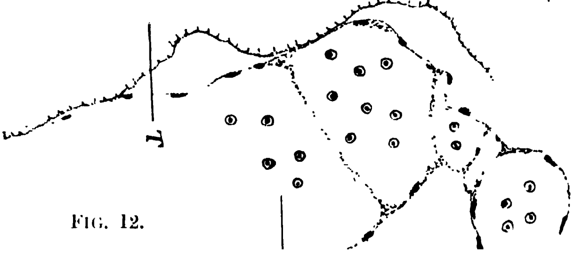


FIG. 12.

PLATE VIII

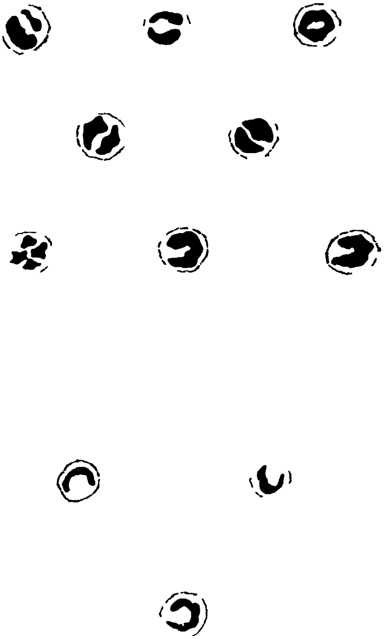


FIG 12 i

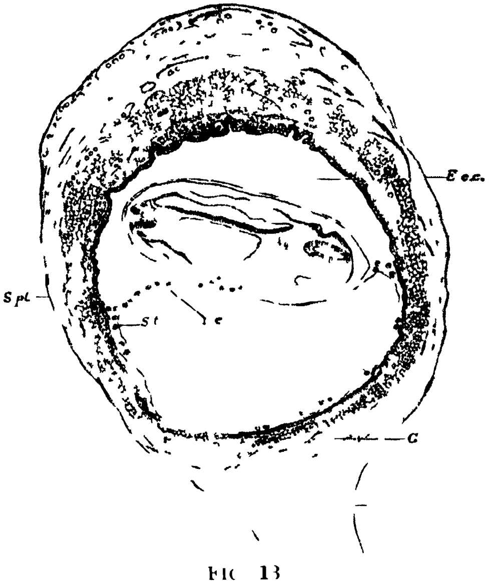


FIG 13

PLATE IX

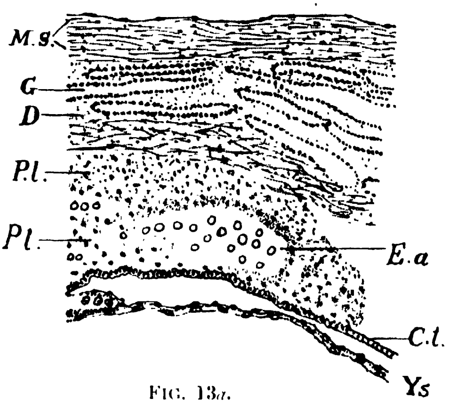


FIG. 13a.

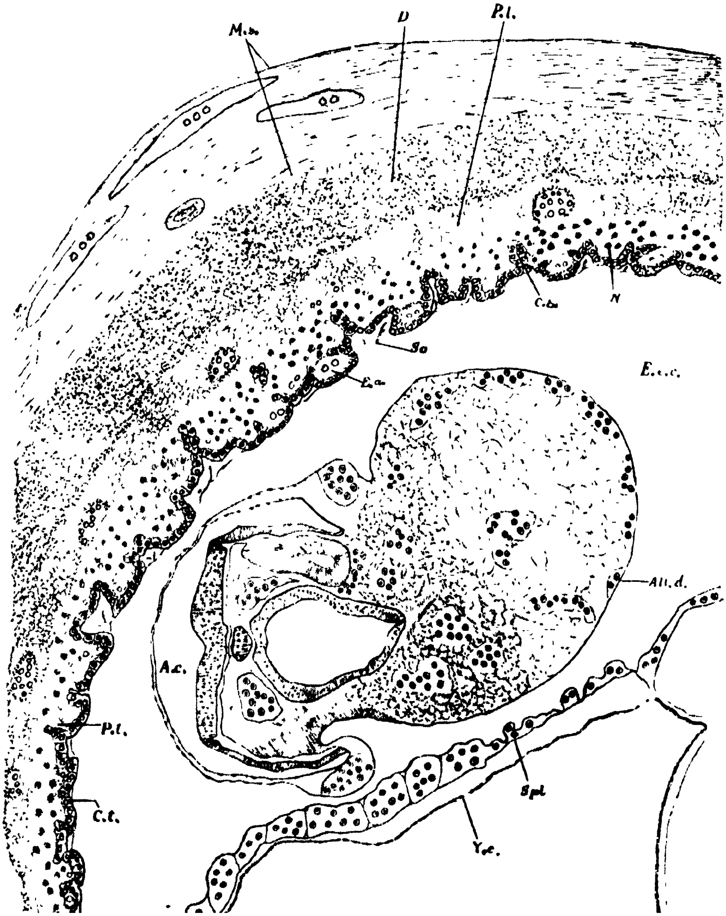


PLATE X

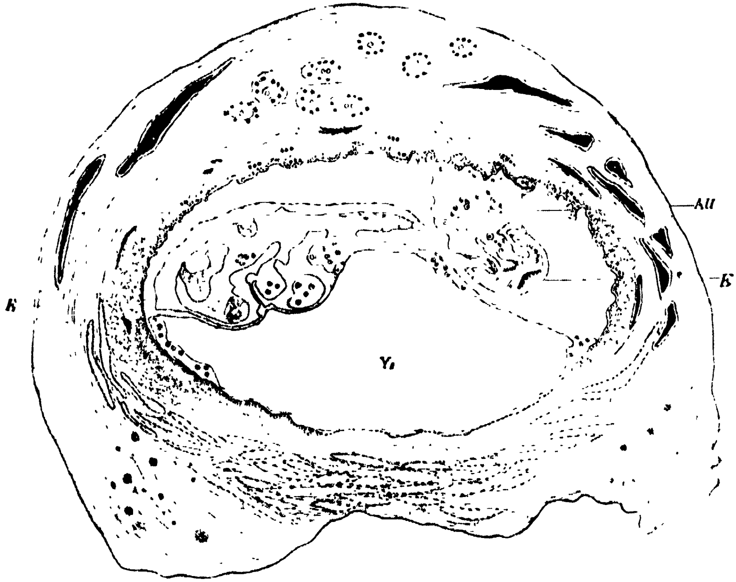


FIG. 15.

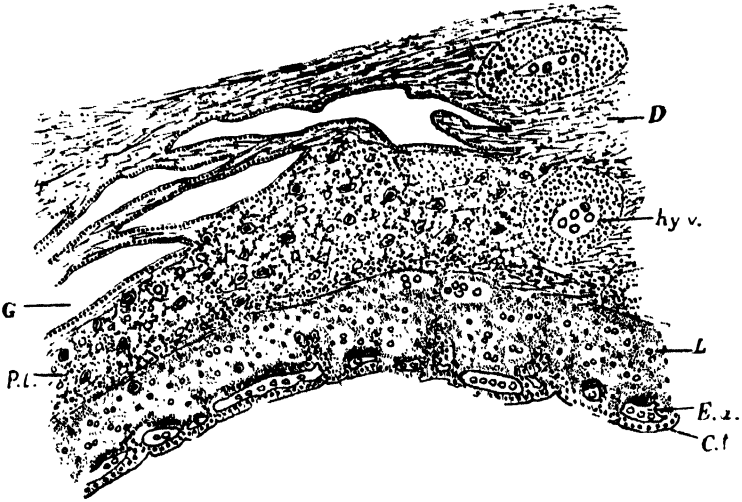


FIG. 15*a*.

PLATE XI

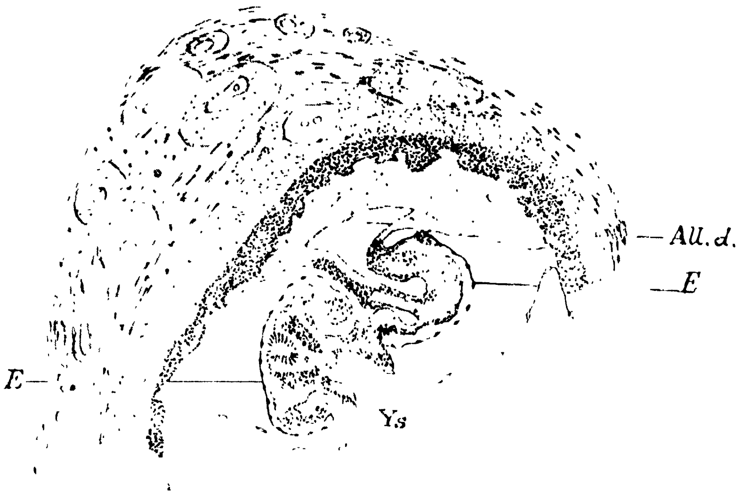


FIG. 16.

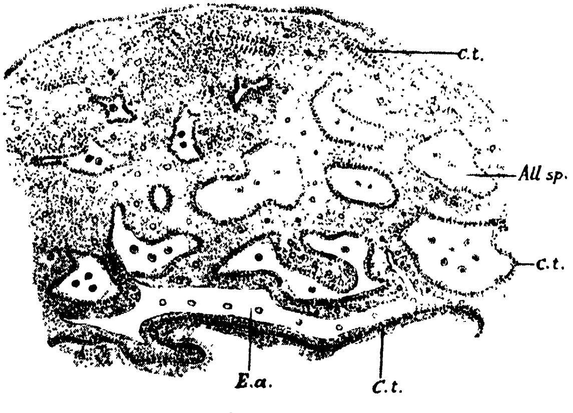


FIG. 16a.

PLATE XII

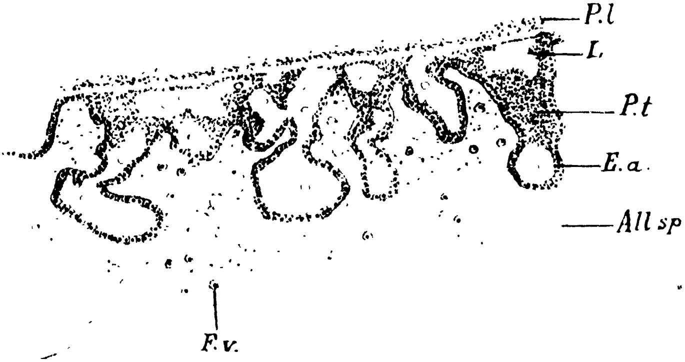


FIG. 17.

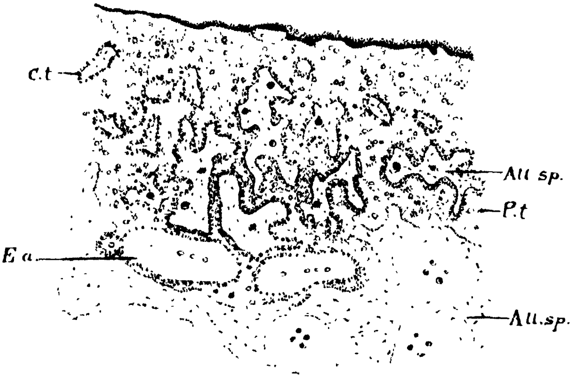


FIG. 17*a*.

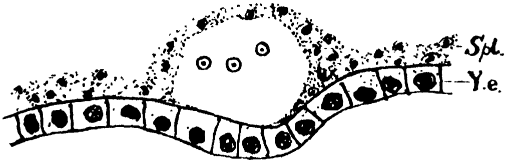


FIG. 18.

PLATE XIII

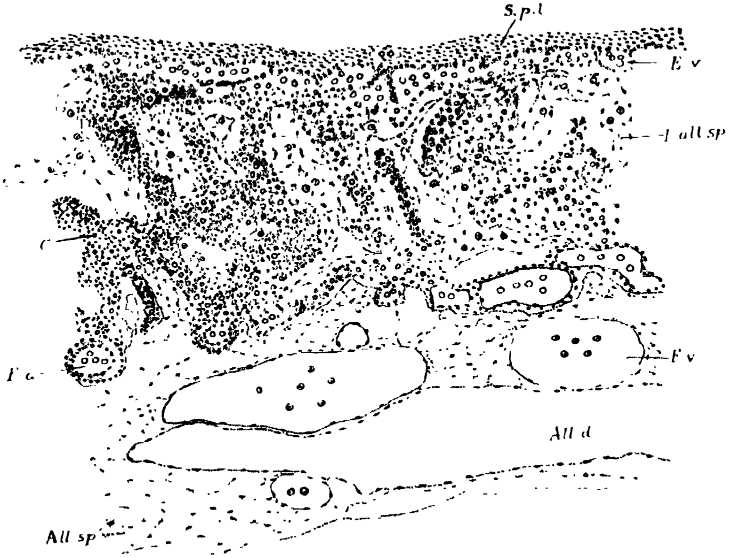


FIG. 19.

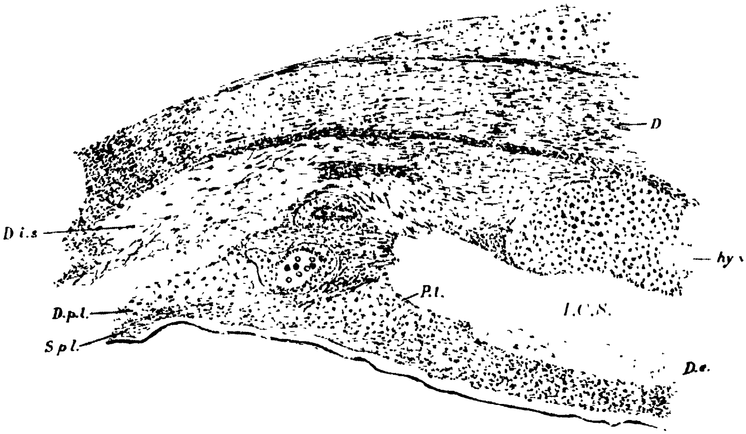


FIG. 20.

PLATE XIV

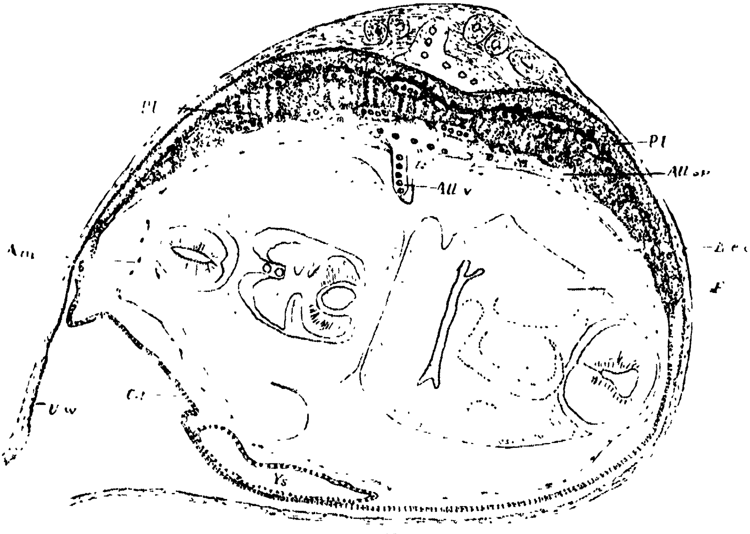


FIG. 21.

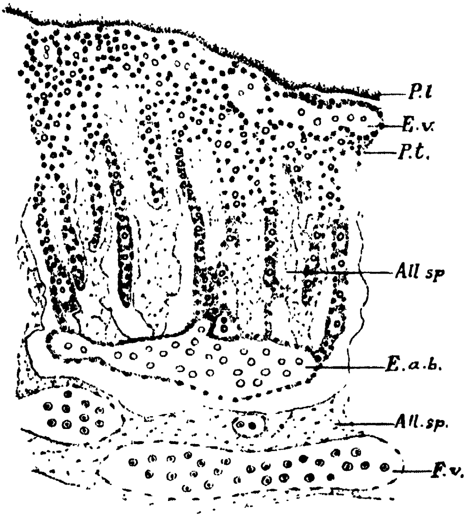


FIG. 21*a*.

PLATE XV

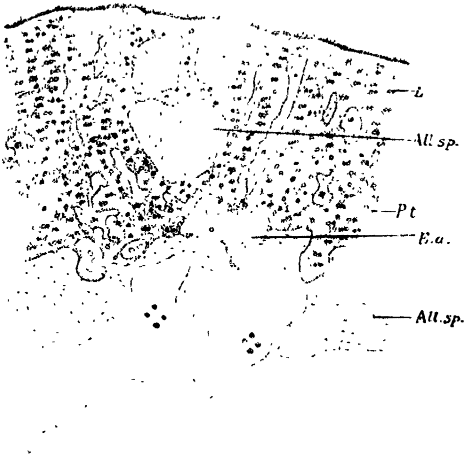


FIG. 21*b*.

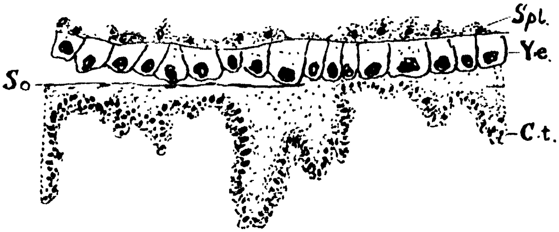


FIG. 21*c*

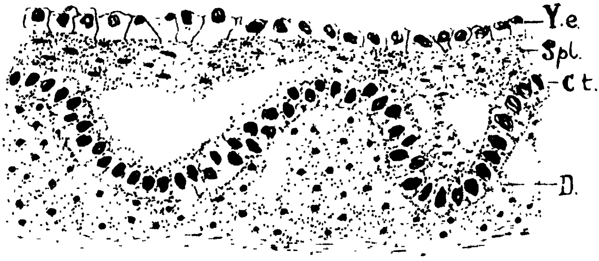


FIG 22*a*.

PLATE XVI

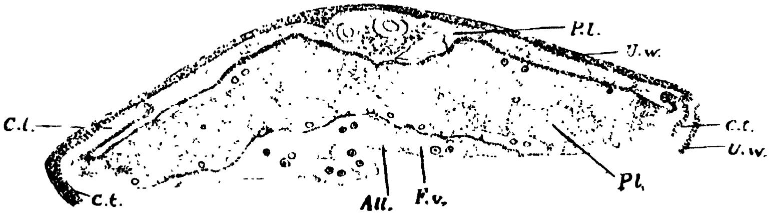


FIG. 22.

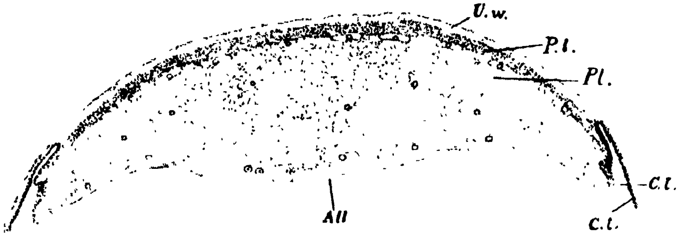


FIG. 23.

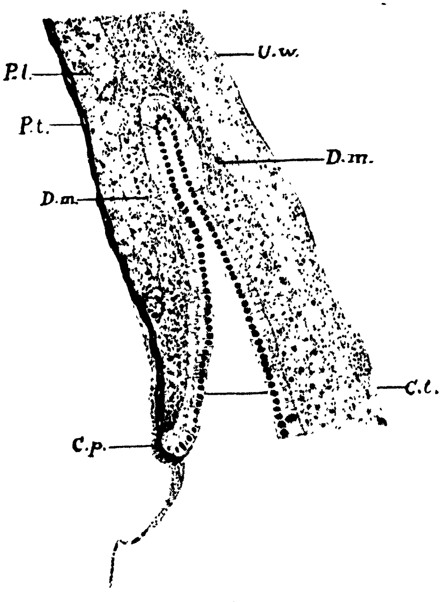


FIG. 23*a*.

PLATE XVII

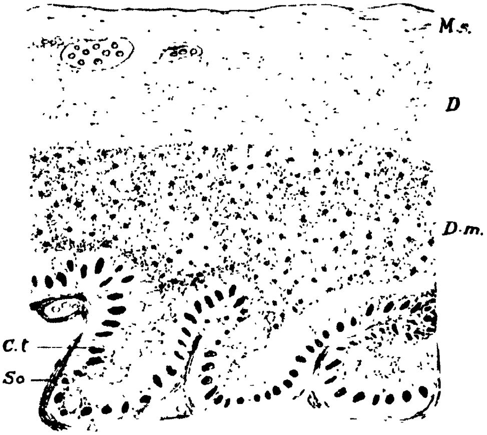


FIG. 23*b*.

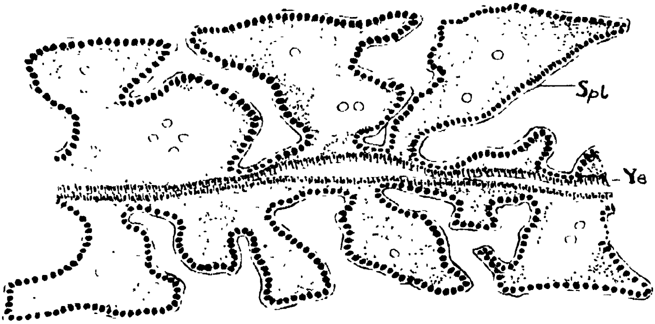


FIG. 23*c*.

THE SPARK SPECTRUM OF MERCURY, Hg II AND Hg III.*

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INTRODUCTION.

Mercury is an element whose spectrum has been the subject of experimental investigation for about a century, and the number of enquiries concerning themselves directly or indirectly with this spectrum is overwhelming. Yet it is only since 1926 that knowledge regarding the structure of its spark spectrum has been accumulated. The first entry in Kayser's *Handbuch der Spectroscopie* under the element mercury refers to a paper by Ch. Wheatstone[1] on the spark spectrum, read before the Nottingham meeting of the British Association in 1835. But the first attempt at its analysis was that of J. A. Carroll[2] who studied the spark spectra of a number of elements homologous with copper, silver and gold. It is true that Rydberg had noted[3] the pair of lines 2847.83 Å and 2226.82 Å as analogous to the principal pairs of ionised cadmium and zinc, but the results of Carroll showed that these lines could not be the first members of the principal series. A little later, R. A. Sawyer[4] in a paper on "The Deep-lying Terms in Two and Three Valence Electron System Spectra" upheld the classification of Rydberg and identified λ 1987.2 and 1662.6 as $6\,^2P_1$—$6\,^2S$ and $6\,^2P_2$—$6\,^2S$. This discrepancy between the results of the two investigators and some interesting phenomena observed by himself induced Paschen[5] to undertake a new detailed analysis of the spectrum. This important investigation confirmed Carroll's work in part and also provided a complete series classification of the doublet spectrum of singly ionised mercury. S. M. Naudé,[6] working in Paschen's laboratory, succeeded in identifying a number of quartet terms and a few doublets. In an attempt to explain the peculiar behaviour of some spark lines of mercury noticed by Prof. B. Venkatesachar,[7] a number of new levels were discovered by the author.[8] At the same time a paper by McLennan, McLay and Crawford[9] appeared in which the spectrum was interpreted on the basis of close j-j coupling. These authors rejected a number of terms given by Paschen and Naudé as insufficiently established and also gave a number of new terms. Some of these coincided with terms which had been found by the author and otherwise interpreted. A consideration of the whole set of terms showed, however, that none of the terms given by Paschen or Naudé needed to be set aside, and the new terms given by McLennan and his co-workers found a natural place among displaced series discovered by the present writer.[10] A close study of the limits approached by these series revealed the fact that Hund's later theory[39] correctly represented their behaviour. A new light was also thus shed on the Hg III spectrum which had been partly analysed by McLennan, McLay and Crawford.[11] The results obtained by the application of these new ideas were presented by the author before the Science Congress Meeting at Patna. Further investigation has led to an extension of the Hg III spectrum in some directions and these results are now included for the first time in this paper. It is proposed to discuss the work of other investigators in so far as it has been utilised in the present inquiry and then give a comprehensive account of all the results obtained by the writer in the course of his work on the spectrum of singly and doubly ionized mercury.

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* Thesis submitted for the M.Sc. Degree of the Mysore University.

EXPERIMENTAL DATA.

Experimental data from a number of sources have been utilised in the present work. The tables of spark lines given by Stiles, Eder and Valenta (to be found in Kayser's *Handbuch*[1]), Déjardin,[12,13] Rasmussen[14] and Ricard[15,16] have been drawn upon, while in the extreme ultra-violet, the observations of Lyman,[17] L. and E. Bloch[18] and particularly J. A. Carroll[2] have been very useful. Stiles[31] and Eder and Valenta employed the condensed spark while Lyman, L. and E. Bloch and J. A. Carroll have used the spark in vacuum. Accordingly their data include lines of Hg III and higher ions. Using the electrodeless discharge in conjunction with a spark gap the length of which is varied, Déjardin and Ricard have classified the lines given by them as belonging to Hg II, Hg III and Hg IV. This method of distinguishing lines belonging to different stages of ionisation is due to L. and E. Bloch whose paper[19] became recently available at Patna through the courtesy of the authorities of the Science College there. A similar classification has been given also by Kimura and Nakamura[20] in the case of prominent spark lines. They employed the method of varying the inductance used in series with the spark gap, whereby the lines due to lower stages of ionisation become strengthened and those due to higher ions become weakened on increasing the inductance. This method has been used also by A. Fowler[21] and by K. R. Rao.[22] See also Gibbs, Vieweg and Gartlein.[23] Although these methods are reliable in the main, the differences between different authors show that caution has to be exercised in interpreting the results. The following table shows the extreme divergence that sometimes exists in the conclusions of different observers. The results obtained by Déjardin[24] by the method of electron collisions have also been utilised in making the comparisons. These are distinguished by writing (El) in parenthesis.

Classification of Hg Spark Lines according to different Observers.

Wave-length	Déjardin	L. and E. Bloch	Kimura and Nakamura	Ricard	Remarks
6149.4	....	Hg II	Hg III	..	2S—3P_2 of Hg II Paschen.
6123.5	....	Hg II	..	..	Usually given as arc line. So also Laffay.[59]
5425.3	....	Hg II	Hg III		3D_2–4F_3 of Hg II Paschen.
4973.6	....	Hg III	..	Hg II	....
4898.7	....	Hg III ?	..	Hg II	Ascribed to Hg II in this work.
4869.9	....	Hg III	..	Hg II	Do.
4866.7	....	Hg III	..	Hg II	Do.
4841.2	....	Hg IV	..	Hg II	....
4600.7	....	Hg IV	..	Hg II	....
4515.7	....	Hg III	..	Hg II	....
4487.5	....	Hg III	..	Hg II	Ascribed to Hg II in this work.
4470.6	....	Hg III	..	Hg II	....
4402.1	Hg II (El)	Hg III	..	Hg II	E_1 *. Ascribed to Hg II in this work.
4385.6	....	Hg IV	..	Hg II	....
4378.6	....	Hg III	..	Hg II	....
4376.2	....	Hg III	..	Hg II	....
4336.9	....	Hg III	..	Hg II	Ascribed to Hg II in this work.
4261.9	....	Hg III	..	Hg II	Do.
4216.7	....	Hg III	..	Hg II	....
4122.1	Hg II (El)	Hg III	..	..	E_1 ....
4032.9	....	Hg III	..	Hg IV	Ascribed to Hg II by Naudé.
3942.6	....	Hg III	..	Hg IV	Do.
3820.6	....	Hg I	Hg II	..	....
3790.4	....	Hg I	Hg II	..	....
3771.0	....	Hg I	Hg II	..	....
3755.0	....	Hg III	Hg II	..	....
3751.7	....	Hg I	Hg II	Hg II	....
3561.7	....	Hg I	Hg II	..	....
3543.7	....	Hg I	Hg II	..	
3362.9	....	Hg III	Hg II	..	....
3332.4	....	Hg III	..	Hg IV	Ascribed to Hg II by Naudé.
3208.2	Hg II (El)	Hg II	Hg III	..	E_1' Do.
2947.1	Hg II (El)	Hg II	Hg III	..	E_1' Do.
2916.3	Hg II (El)	Hg II	Hg III	..	E_1 Do.
2817.9	....	Hg III	..	Hg II	....
2809.4	....	Hg III	..	Hg II	....

* E_1 and E_1' indicate lower and higher degrees of excitation in the Hg II spectrum.

Wave-length	Déjardin	L. and E. Bloch	Kimura and Nakamura	Ricard	Remarks
2702.5	Hg II; Hg II (El)	Hg II	Hg III	..	E_1 ? Ascribed to Hg II in this work.
2683.0	Hg II	Hg IV	..	..	....
2642.0	Hg I	Hg III ?	..	..	....
2628.1	Hg II	Hg III	..	..	Ascribed to Hg II by Paschen.
2608.6	Hg III	Hg IV	..	..	....
2599.5	Hg III	Hg IV	..	..	....
2598.5	Hg II	Hg IV	..	..	....
2578.9	Hg I	Hg IV	..	..	....
2574.9	Hg II; Hg II (El)	Hg III	..	..	E_1 ? Ascribed to Hg II by Naudé.
2571.8	Hg I	Hg IV	..	..	....
2563.9	Hg I	Hg IV	..	..	....
2541.2	Hg II ?	Hg IV	..	..	....
2524.7	Hg III	Hg II ?	..	..	Ascribed to Hg II in this work.
2507.5	Hg I	Hg II	..	..	....
2502.8	Hg III ?	Hg II	..	..	....
2492.1	Hg II	Hg II	Hg III	..	$2S$–$4P_2$ of Hg II according to Paschen.
2458.5	Hg II	Hg III	..	..	....
2451.2	Hg II or Hg III	Hg IV	..	..	....
2448.6	Hg III	Hg IV	..	..	....
2414.1	Hg II; Hg II (El)	Hg II	Hg III	..	E_1 Ascribed to Hg II by Naudé.
2407.4	Hg II; Hg II (El)	Hg II	Hg III	..	Do.
2340.6	Hg I	Hg II	Hg III	..	....
2315.0	Hg I	Hg II	Hg III	..	....
2300.0	Hg I; Hg II (El)	..	..	..	E_1'
2296.4	Hg II	Hg II	Hg III	..	Ascribed to Hg II by Naudé.
2263.9	Hg II; Hg II (El)	Hg II	Hg III	..	E_1

A perusal of the above comparison shows the extreme diversity which the results of different observers display in the case of some lines. It is astonishing to find some lines ascribed to the arc by one investigator and to trebly ionised mercury by another. There are cases in which the same observer gets different results by different methods. But in general one can see that lines due to high terms in any spectrum are likely to be ascribed to the next higher stage of ionisation. In fact many lines classified by Naudé or in this work as transitions involving the high d^9 sd ^4D terms have been ascribed to Hg III or sometimes even to Hg IV by L. and E. Bloch. Some lines ascribed to Hg III or Hg IV by the Blochs or by Déjardin have been included in the present work, particularly in view of the large number of cases in which L. and E. Bloch give a line as belonging to Hg III or Hg IV while it is ascribed to Hg II by Ricard. Especially in the case of negative terms, the likelihood of a line appearing to belong to the next stage of ionisation is quite high. Taking these facts into consideration it may be remarked in passing that the objection raised by Déjardin and Ricard[25] against Paschen's classification of λ 3312 on the ground that it belongs to Hg III as observed by the method of electron impact loses much of its weight since this line involves a high term. The similar objection of Ricard[16] that in the classification of Naudé appear lines that surely belong to Hg IV must also be examined with caution and with due regard to their mode of production in the source used by Naudé. This can be done when we have described the processes in the hollow cathode discharge used by Paschen and Naudé; a discussion of this source is also important in the present work since much of the material for this investigation has been first sought in the lists given by these authors. The results of the other investigators mentioned at the beginning of this section have only been utilized to supplement these data wherever necessary. Hence we will in the next section discuss the hollow cathode glow discharge and the peculiar advantages which have led to its extensive use in modern days.

THE HOLLOW CATHODE DISCHARGE.

The hollow cathode was used in a spectroscopic source first by Paschen.[26] It usually consists of a hollow cylinder of the metal whose spectrum is to be excited if it is one that sputters sufficiently for the purpose, or the metal is placed in a powdered condition inside a hollow cylinder of carbon or molybdenum. It was shown by Schüler that one or both sides of the cylinder could be closed leaving a small slit on the side facing the window. Takahashi[27] in his work on the spark spectrum of cadmium used a carbon cylinder, one end of which was closed, and the cadmium was placed in a powdered form between the closed end and a perforated diaphragm placed across the cathode at about one-fourth of its length from the closed side. In the form of the tube used by Paschen for mercury the carbon hollow cathode was held in an iron ring and the anode was made of sheet iron. The tube was closed by a quartz window. A D.C. voltage of about 1500 volts was applied to the tube and the current was kept low at about 20 milliamps. Pure helium was circulated through the tube. When the carbon cathode had been kept incandescent for some time by means of a strong current and the helium pure, carbon lines and bands entirely disappeared and only mercury lines were present. The mercury vaporised sufficiently by the heat of the cathode leads and entered the hollow cylinder. The helium was freed from hydrogen after its exit from the tube by passing it over heated copper oxide and then further purified by passing through charcoal cooled by liquid air. The purified helium was again led into the tube and kept slowly circulating through the apparatus. The mercury can also be excited without the presence of helium and Naudé has in this way observed more lines than could be obtained with helium.

The conditions obtaining within the hollow cathode are somewhat different from those in an ordinary discharge.[60] First in the inside of the cathode is found the cathode sheath, and then there is the Crooke's dark space in the form of an annulus and in the middle of this is the cathode glow surrounding the axis of the cylinder. The purer the helium, the brighter is this glow. The pressure at which the discharge is chiefly confined to the inside of the cathode depends upon the diameter of the cathode and the nature of the gas: the most suitable pressure is that at which the normal cathode dark space has a length equal to the inner radius of the cathode cylinder. The region inside the negative glow is free from electric fields so that ions of the metal can remain in considerable numbers and radiate freely even from states of large quantum number. The higher members of series are strongly and fully developed. But for this circumstance, the singlet levels in Al II could not have been identified, as Paschen[28] points out in his paper. Another advantage is that the lines are not broadened on account of the Stark effect and the temperature can be kept low so that the lines are sharp. It is for this reason that the hollow cathode in the modified form given by Schüler is so often used for investigating the hyperfine structure of spectral lines.

The mode of excitation is envisaged in the following manner by Paschen and Frerichs.[28] The metal atoms must be sparse enough for the current to be mainly carried by the rare gas atoms. Under these circumstances a considerable number of metal atoms will be present in the negative glow in the form of ions while in the positive glow or in a side-tube near the anode they are present in the neutral state. The energy of the metastable state of the rare gas used is then communicated to the metal atoms by impacts of the second kind with metastable rare gas atoms as some would have it, or by electrons whose energy is limited by that of the metastable state of the rare gas as Paschen is inclined to consider. Even if the excitation is by the electrons the available energy is not greater than that of the metastable state of the rare gas since the electrons cannot reach a higher energy and yet remain without giving it up to rare gas atoms, as has been shown by Franck and Hertz. That the available energy is limited to that of the metastable state of the rare gas is borne out by the experiments of Frerichs conducted at the suggestion of Paschen with Al, Mg, Zn and Cd and using He, Ne and A in turn. From these experiments Paschen concludes that the metal atom is excited from the normal state of the ion inside the negative glow whereas in the positive glow or in a side tube it is excited from the normal or metastable level of the neutral state. It was found that lines involving an initial level whose term value is less than T_0—E, where T_0 is the term value of the normal state of the ion and E is the available energy of the rare gas atom, could not be excited. E was found to be the energy of the metastable state of the rare gas.

Applying these considerations to mercury[29] we should expect no lines to be emitted in the presence of helium such that their initial level has a term value smaller than 151280—159830= —8550. The smallest term found by Naudé is —8019. Even the lowest excited states of Hg III are much beyond the small margin of available excess energy. Accordingly the line 3312 classified by Paschen as belonging to Hg II must be taken to be correctly identified and Déjardin's results will have to be explained on the ground that a weak transition like that represented by 3312 [$Y(^2P_{3/2})$—$A(D_{5/2})$] might have escaped notice at lower voltages. This view is further strengthened by the fact that even the strongest lines classified by McLennan, McLay and Crawford[11] as belonging to Hg III have not appeared in Paschen's list. Hence it is quite certain that lines like 3312 and 3090 which are not among the classified lines of Hg III could not really belong to that spectrum since they appear in the hollow cathode discharge in the presence of helium. It is also significant that the two lines 3312 and 3090 which appear at the same voltage according to Déjardin have the same final level according to Paschen (Y—A and Y—5S) and their initial levels are also near. We must also remember that Déjardin has not obtained even the strongest classified lines of Hg III by the method of electron impact. It is therefore safe to take Paschen's allocation as correct. A similar argument applies to the objection raised by Ricard[16] against the classification of some lines given by Naudé, on the ground that they belong to Hg IV. Some of these, *viz.*, λ 3942.59, 3402.77 and 2957.36 appear in the presence of helium.[6] When even the prominent lines of Hg III do not appear in the hollow cathode discharge with helium, it is incredible that lines of Hg IV can be produced. When there is pure mercury with no helium, the excitation depends only on the electron velocity and lines of greater excitation may appear in the discharge, just as in pure helium the excitation is sufficiently high to produce its spark lines. According to Paschen, lines of excitation energy equal to 49.4 volts have been observed in pure helium. The appearance of two of the strongest lines of Hg III (*viz.*, 2354.33 and 2244.42) in the hollow cathode discharge in pure mercury vapour[6] is in accordance with Paschen's conclusion, for the excitation energy of these two lines measured from the ground state of the normal atom is about 37 volts. Even stronger lines, when their excitation energy is greater, do not appear in Naudé's list. It is therefore improbable that the lines of Hg IV have crept into his classification. Ricard's objection also loses weight from the fact that some of these same lines of Naudé, which he attributes to Hg IV, are given as belonging to Hg III by L. and E. Bloch.

THE PRESENT INVESTIGATION.

As has already been noticed in the Introduction, Carroll[2] was the first to attempt an analysis of the first spark spectrum of mercury. Although the results independently obtained by Sawyer[4] cast doubts on the correctness of his classification, Paschen's analysis[5] proved the general accuracy of Carroll's work and provided at the same time an extensive investigation of the doublet spectrum, built on the $d^{10}\,{}^1S_0$ state of the Hg^{++} ion. The lines used by Sawyer as the first pair of the principal series have since been otherwise classified, one of them being attributed to Hg III.[11] A few doublet terms arising from the d^9s configuration of the ion were also given by Paschen. Among these were the important metastable inverted doublet D terms due to the d^9s^2 configuration. The combinations with these terms were the basis for the further work of Naudé who discovered a number of terms resulting from the d^9sp and d^9sd states of Hg II. In the meanwhile the attention of the writer was drawn to this spectrum by the peculiarities noticed by Prof. B. Venkatesachar in the behaviour of certain Hg II lines in an arc discharge. At the kind suggestion of Prof. Venkatesachar, this enquiry was undertaken with the object of explaining this peculiar behaviour. His encouragement is also responsible for the continuation of the work after the original object had been attained.[8]

While studying the influence of the density of vapour in the mercury arc on the relative intensity of radiated spectral lines, Venkatesachar found[7] that a few spark lines increased in intensity when the vapour density was lowered, while other spark lines appearing in the arc decreased in intensity under these conditions. Two photographs were taken in juxtaposition, and with the same time of exposure, one with the anode alone cooled and the other with the cathode also cooled by a jet of air. A comparison of these two photographs showed that the spark line λ 2262 was most conspicuously brightened on decreasing the vapour density by cooling with the air jet. In this respect it resembled the forbidden line 2270 (6^1S_0—6^3P_2) of Hg I. The spark lines 2053 and 2027 were also increased in intensity under the same conditions. When the region near the cathode was focussed on the slit of the spectrograph the lines 2262, 2053, 2027 and 1974 were all enhanced near the cathode, but differed from other spark lines in that they reached greater heights from the cathode. 2262 was the most prominent line in this respect. Because of its greater length it was inferred that 2262 required less excitation energy than the other spark lines mentioned above. It was also found that 2262, 2053 and 2027 were of the same intensity in both the hollow cathode discharge in pure mercury and in the presence of helium as recorded by Naudé. Now Naudé had classified 2053 and 2027 as transitions from $5d^96s6p\,{}^1\overline{D}_{7/2}$ and ${}^4F_{5/2}$ to the metastable $5d^96s^2\,{}^2D_{5/2}$ level, while 2262 was left unclassified. The experimental facts detailed above pointed to the conclusions that 2262 must be a transition to $5d^96s^2\,{}^2D_{5/2}$ from a level deeper than ${}^4F_{7/2}$ and ${}^4\overline{D}_{7/2}$. The initial level was thus found to have the value 71575 and its other combinations were all favourable to its being identified as $5d^96s6p\,{}^2D_{5/2}$. The spectrogram revealed also the fact that λ 2339 was similar to 2262 and it was found from Naudé's list that it was equally intense in the hollow cathode discharge in pure mercury and in the presence of helium. It was accordingly classified as $5d^96s^2\,{}^2D_{5/2}$—$5d^96s6p\,{}^2\overline{D}_{3/2}$. This classification is confirmed by a comparison with the arc spectrum of copper analysed by L. A. Sommer.[30]

	Cu I.	Diff.	Hg II.	Diff.
$5d^96s^2\,{}^2D_{5/2}$ ..	51105.5	2042.9	115766	15038
$5d^96s^2\,{}^2D_{3/2}$ ..	49062.6		100728	
$5d^96s6p\,2\overline{D}_{3/2}$ ..	16135.4	425.6	73032	1457
$5d^96s6p\,{}^2\overline{D}_{5/2}$ ..	15709.8		71575	

The doublet difference 1457 when inserted in Landé's doublet formula for penetrating orbits yields for the screening constant the value 4.49. This is a likely value in itself and it is further confirmed by the fact that the doublet difference between the ${}^2P$ terms of the same configuration found by Paschen gives 4.09 as the value of the screening constant (*Note* :—These values have been calculated on the basis of more recent values of the constants appearing in Landé's formula $\Delta\nu = \frac{R\alpha^2 Z^2_i Z^2_a}{n^{*3}\, l(l+1)}$. The values given in *Zs. f. Phys.*, **73**, 414, 1931 were based upon old values of the constants). The frequency difference 1457 appears between a number of pairs of lines of appreciable intensity so that the reality of the levels deduced from 2262 and 2339 may now be taken to be established. The large number of combinations with these levels ($^2D_{5/2}$ and $^2D_{3/2}$) also favours this conclusion.

By the recognition of the frequency difference 1457, a number of new terms were found; particularly interesting were four terms denoted by T in the paper above referred to.[8] They were found to follow the Ritz formula approximately when their values were all diminished by a constant amount. On the basis of the value of this constant and the combining properties of the terms they were tentatively ascribed to the configurations $5d^9 6pnp$, but considerations will be advanced in the present work leading to a more certain allocation. But this does not in any way alter the values of the terms previously given. Accordingly, the list of previously classified lines will not be repeated here, but we will only refer to the previously published papers.[8,10] A few remarks might, however, be made about the accuracy with which calculated values of the wave-numbers of transitions agree with observed wave-numbers.

As remarked before, the results of Paschen and Naudé were the basis on which the new investigations proceeded. The term values given by these authors have been used in deriving the values of the new terms. Now Paschen remarks in his paper that the wave-lengths were measured against the normals of Stiles,[31] but the accuracy of measurement was not large since only a one-metre grating and glass and quartz prism spectrographs were available. The measurements of Naudé also are of the same order of accuracy. Hence the term values given by Paschen and Naudé may be sometimes in error by one or two wave-numbers, so that calculated values of combinations may be in error by 3 to 4 wave-numbers. The errors of measurement in individual lines may also amount to one or two wave-numbers; in the case of weak or diffuse lines it may be more. It is also known that lines are shifted in the hollow cathode discharge by about 2 wave-numbers. It is a noteworthy fact that various observers[12,15] who have taken the values of Stiles as standard yet obtain differences of the order of 0.5Å in a number of lines. This absence of agreement between different observers may be due to the width and complexity of the mercury lines which have a complicated hyperfine structure and large isotope displacements, so that what is taken as the centre of a line by different observers is likely to differ with the character of the source used and other factors. It is remarkable that two observers like Stiles and Cardaun[32] both of whom give results to 3 places of decimals agree to within 0.1Å in the case of arc lines, while in spark lines they differ by 0.2 to 0.5A. (See *e.g.*, p. 674, Kayser's *Handbuch der Spectroscopie*, VII, 2.) On account of this difficulty, the calculated and observed values differ by one or two units and sometimes even four or six units, both in the analysis of Paschen and Naudé and in the present work. McLennan, McLay and Crawford, using the same data, obtain a somewhat better agreement by striking out some combinations and altering the term values to fit the rest better. But, considering the differences in the wave-lengths given by different observers who claim similar accuracy, it is somewhat arbitrary to follow such a procedure and hence even combinations showing somewhat large deviations have been allowed to remain unexpunged in the present work. There is, therefore, the possibility that a few of the combinations may be spurious or accidental, but the reality of the terms is rendered indubitable by the large number of more accurate combinations. Since the results of a large number of investigators have been utilised, nothing better is possible at present. The intensities of the lines are also not strictly to be compared since each observer has used a different scale and the conditions of the experiments are also different. Déjardin has also shown that the wave-length of the same line differs in the arc and spark while the variation in relative intensity with different conditions of excitation is of course well known.

DISPLACED SERIES.

Continuing the investigation described in the previous section an attempt was made to explain a number of constant frequency differences noted by Déjardin and Ricard[25] (*Comptes Rendus*, **190**, 429, 1930) which were mostly unaccounted for by Naudé's results. A number of terms had been found in this way and some of them could be assigned to electronic configurations. But there were others whose combining properties and magnitudes were such that the corresponding electron configurations could not be determined. In the meanwhile the paper by McLennan, McLay and Crawford[9] came to hand. In this paper, the above authors had rejected a number of terms given by Paschen and Naudé, slightly altered the values of some others and rearranged them all into a scheme based on the assumption of close j-j coupling. They had also given eleven new terms, of which three coincided with terms found by the author, one with a term given by Ricard, and another was based on only one combination. This last term was untenable since λ 2339 which was the only line given by McLennan *et al.* as involving this term, had already been interpreted by the writer as $5d^96s^2\ {}^2D_{5/2} - 5d^96s6p\ {}^2\bar{D}_{3/2}$.

Considering the number of accurate combinations given by Naudé and some others found in this work, the terms given by Naudé and Paschen appeared to be real and there appeared no reason for rejecting them. But if they were retained those new terms found by McLennan and his co-workers which were ascribed to the $5d^96s6p$ configuration could find no place there. The problem was, however, solved by the terms which had been found by the author and whose combining properties as noted before had been such that their allocation to electron configurations was difficult. For, on comparing the values of these terms with a Rydberg table it was seen that they would follow a series formula if their values deduced from the combination principle were reduced by certain constant amounts. In this way a number of displaced series having excited states of Hg III as limits were found. Careful search revealed a large number of members in each series. Apart from the series of this type that have been already published in *Zs. f. Phys.*, **78**, 541, 1932, and are not repeated here, Table I contains two new series, one of which includes the T-terms above referred to as following a displaced series formula. These series and their limits will be discussed later on.

TABLE I.

n	$T_{5/2}$ Series.	${}^2D_{5/2}$ Series.
3	69887	71693
4	58087	56012
5	49892	48244 ?
6	45096	44102 ?
7	42039	
8	40017	
A	33562	?
Terms of Hg III as limit	${}^3D_3$	?

Some of the line series arising from combinations with each of these series of terms are set forth in the tables that follow. In each case the intensity as given by the original observer, the wave-length (corrected to I.Å whenever the original data were on the Rowland scale), the corresponding wave-number, the wave-number calculated from the combination, and the name of the observer are given. Some intensity anomalies noticeable in these tables from one member to another of the

TABLE
THE $^4P_{5/2}$

n	3	4	5	6	7
Terms.	74239	55978	47352	42361	39290
$^2D^1_{5/2}$ 115766	(8) 2407.35 41526.8 41527 Naudé	(10) 1672.627 59785.6 59788 Naudé Blend	(3) 1461.4 68427 68414 Carroll	(0) 1362.4 73400 73405 Carroll	(1) 1307.9 76459 76476 Carroll
$^4D^3_{7/2}$ 18566	(10) 1796.20 55673.1 55673 Naudé	....	(8) 3473.01 28785.2 28786 Naudé	(10) 4200.76 23798.5 23795 Naudé	(7) 4823.65 20725.4 20724 Naudé
$^4D^3_{5/2}$ 14569	(8) 1675.898 59669.4 59670 Naudé	(8) 2414.13 41410.3 41409 Naudé	(3) 3049.42 32783.6 32783 Naudé	(7) 3596.68 27795.5 27792 Naudé	(3) 4044.10 24720.4 24721 Naudé
$^4D^3_{3/2}$ 11146	(0) 1584.8 63100 63093 Carroll	(1) 2229.86 44831.9 44832 Naudé	....	....	(1) 3552.61 28140.3 28144 Naudé
$3_3\frac{1}{2}$ 15981	(1) 1716.6 58255 58258 Lyman	(1) 2499.37 39998.0 39997 Déjardin	(3) 3186.85 31369.9 31371 Naudé	(1u) 3789.818 26379.0 26380 Stiles	(1) 4289.726 23305.0 23309 Stiles
A($D_{5/2}$) 15014	....	....	(2) 3090.98 32342.8 32338 Paschen	(1) 3656.25 27342.7 27347 Eder & Val	(1) 4117.319 24280.8 24276 Stiles
B($D_{3/2}$) 29094	(5) 2214.47 45143.4 45145 Déjardin (Hg III)	(1) 3717.85 26889.6 26884 Eder & Val	(3) 5475.0 18259.8 18258 Naudé	(3d) 7538.1 13262 13267 Rasmussen	....
$a_{5/2}$ 4633	(2) 1436.6 69609 69606 Carroll	(0) 1947.65 51343.9 51345 Naudé	....	(0) 2649.80 37727.5 37728 Déjardin	....

II.
SERIES.

8	9	10	11	12	13
37279	35890	34917	34161	33624	33179
....	(2) 1251.7 79892 79876 Carroll	....	....	....	....
(3) 5342.4 18713 18713 Paschen Blend	Falls on 5770	(0) 6114 16351 16351 Paschen	....	(4) 6638.7 15059 15058 Rasmussen	....
(12) 4402.06 22710.3 22710 Naudé	(1) 4688.92 21320.9 21321 Eder & Val	(2) 4912.82 20349.2 20348 Eder & Val	(5) 5102.42 19593.1 19592 Naudé	....	(2) 5371.42 18611.9 18610 Naudé Blend
....	(3) 4040.40 24743.1 24744 Naudé	(1) 4205.546 23771.4 23771 Stiles	Falls on 4343.64	(12) 4454.33 22473.8 22478 Naudé	(7) 4537.36 22033.1 22033 Naudé
....	(2) 5020.72 19911.9 19909 Eder & Val	(3) 5279.13 18937.3 18936 Eder & Val	(1) 5499.8 18177.4 18180 Naudé	(1) 5666.37 17643.1 17643 Naudé	....
(2) 4489.732 22266.8 22265 Stiles	....	....	(8) 5222.81 19141.5 19147 Paschen Blend	(2) 5371.42 18611.9 18610 Naudé Blend	(3) 5503.8 18164.2 18165 Naudé
....	....	....	....	....	....
(2) 3062.00 32648.9 32646 Naudé	....	....	(15) 3385.25 29531.5 29528 Naudé Blend	(2) 3448.745 28987.8 28991 Stiles	(2) 3502.10 28546.2 28546 Naudé

TABLE
THE $^4F_{7/2}$

n	3	4	5	6	7
	74356	56094	48568	43809	40844
$^2D^1_{5/2}$ 115766	(8) 2414.13 41410.3 41410 Naudé	(8) 1675.90 59670 59672 Naudé	(2) 1488.3 67191 67198 Carroll	....	(1) 1334.6 ? 74929 74922 Carroll (Carbon ?)
$^4D^3_{7/2}$ 18566	(3) 1792.46 55789.2 55790 Naudé	(1) 2663.79 37529.3 37528 Naudé	(10) 3332.11 30002.4 30002 Naudé (Blend)	(5) 3960.24 25243.9 25243 Naudé	(20) 4487.48 22278.0 22278 Naudé (Blend)
$^4D^3_{5/2}$ 14569	(10) 1672.617 59785.6 59787 Naudé	(8) 2407.35 41526.8 41525 Naudé	(3) 2940.50 33997.9 33999 Naudé	(3) 3418.72 29242.3 29240 Naudé	(20) 3804.77 26275.3 26275 Naudé (Blend)
$3_3\frac{1}{2}$ (McLennan) 15981	....	(5) 2492.09 40114.9 40113 Paschen	(5) 3067.75 32587.7 32587 Ricard	(1) 3593.05 27823.6 27828 Eder & Val	(2) 4020.85 24863.4 24863 Eder & Val
$A(D_{5/2})$ 15014 (Paschen)	....	(2) 2433.87 41074.3 41080 Déjardin	....	(4) 3471.555 28797.3 28795 Stiles	(1) 3870.15 25831.5 25830 Eder & Val
$a_{5/2}$ 4633 (Naudé)	(0) 1434.2 69725 69723 Carroll	(1d) 1943.49 51453.8 51461 ? Déjardin	(1) 2275.43 43934.1 43935 Huff	(1) 2551.67 39178.3 39176 Déjardin	....

III.
SERIES.

8	9	10	11	12	13
38961	37635	36695	36015	35425	34979
(1) 1302.1 76799 76805 Carroll	(0) 1279.7 78143 78131 Carroll (Blend)	(1) 1264.7 79071 79071 Carroll	(1) 1254.0 79745 79751 Carroll	(1) 1244.7 80341 80341 Carroll	(0) 1237.7 80797 80787 Carroll
(1) 4901.98 20394.2 20395 Eder & Val	(1) 5242.63 19069.1 19069 Eder & Val	(1) 5514.5 18129.0 18129 Naudé	(2) 5729.22 17449.5 17449 Naudé (Blend)	....	(5) 6089.8 16416 16413 Rasmussen
(1) 4098.467 24392.5 24392 Stiles	(2) 4333.21 23071.1 23066 Naudé (Blend)	(12) 4518.59 22124.6 22126 Naudé (Blend)	(1) 4661.625 21445.7 21446 Stiles	....	(1) 4898.789 20407.6 20410 Stiles
....	(1) 4616.32 21656.2 21654 Eder & Val	(8) 4825.62 20716.9 20714 Naudé	(1) 4991.155 20029.9 20034 Stiles	(1) 5141.33 19444.8 19444 Eder & Val	....
(3) 4175.628 23941.8 23947 Stiles	(2) 4420.43 22615.9 22621 Eder & Val	(5) 4609.72 21687.2 21681 Naudé (Blend)	....	(1) 4898.789 20407.6 20411 Stiles (Blend)	(2u) 5008.42 19960.8 19965 Eder & Val
....	....	....	....	....	....

TABLE IV.

THE $^4\overline{D}_{7/2}$ SERIES.

n	3	4	5	6	7	8	9
	67069	49354	42306	38714	36608	35158	34090
$^2D^1_{5/2}$ 115766	(10) 2052.929 48695.3 48697 Naudé	....	(9) 1361.307 73458.8 73460 Paschen	(0) 1297.8 77052 77052 Carroll	....	....	....
$^4D^3_{7/2}$ 18566	....	(6) 3247.09 30787.9 30788 Naudé	(5) 4211.64 23737.0 23740 Naudé	(3) 4961.89 20148.0 20148 Naudé	(5) 5540.95 18042.4 18042 Naudé	(2d) 6026.0 16590 16592 Rasmussen	(1) 6440.4 15523 15524 Rasmussen
$^4D^3_{5/2}$ 14569	(4) 1904.755 52500.2 52500 Naudé	(1) 2874.00 34784.5 34785 Naudé	(5) 3604.09 27738.4 27737 Naudé	(9) 4140.38 24145.6 24145 Naudé	(12) 4536.43 22037.6 22039 Naudé	(8) 4855.72 20588.5 20589 Paschen	(1u) 5121.02 19522.0 19521 Stark
$^4\overline{P}_{5/2}$ 23451	(4) 2291.92 43618.1 43618 Déjardin	(3) 3859.75 25901.1 25903 Eder & Val	....	(3) 6553.3 15255 15263 Rasmussen	....	....	....
$4\ ^2D_3$ 25702	(3) 2416.29 41373.2 41367 Naudé	(12) 4227.29 23650.2 23652 Naudé	(6) 6017.2 16614 16604 Rasmussen	....	....	....	....
$5\ ^2D_3$ 16582	(2) 1980.80 50484.6 50487 Déjardin	(1) 3050.88 32767.9 32772 Eder & Val	(1) 3887.079 25719.0 25724 Stiles	(4) 4516.23 22136.2 22132 Eder & Val	(1) 4992.132 20026.0 20026 Stiles	....	....

TABLE V

THE $^2D_{5/2}$ SERIES.

n	3	4	5	6	7	8	9	10
	71575	55622	47244	42620	40036	38160	36787	35924
$^2D^1_{5/2}$ 115766	(10) 2262.23 44190.4 44191 Naudé	(2) 1662.7 60144 60144 Carroll	(1) 1459.4 68521 68522 Carroll	(1) 1367.2 73142 73146 Carroll	(0) 1320.4 75734 75730 Carroll	(1) 1288.3 77622 77606 Carroll	(1) 1266.1 78983 78979 Carroll	....
$^2D^1_{3/2}$ 100728	(1) 3428.36 29160 29153 Stark	(1) 2216.31 45106.0 45106 Déjardin	(½) 1870.783 53482.1 53484 Naudé	(2) 1720.7 58116 58108 Lyman	(7) 1647.4 60702 60692 Carroll (Blend)	....	....	....
$^4D^3_{7/2}$ 18566	(0) 1886.60 53005.4 53009 Déjardin	....	(3) 3486.441 28674.4 28678 Stiles	(7) 4156.68 24050.9 24054 Naudé	(6) 4656.17 21470.9 21470 Naudé	(5) 5102.42 19593.1 19594 Naudé	....	....
$^4D^3_{5/2}$ 14569	....	....	....	(1) 3564.15 28049.2 28051 Stark	(10) 3925.65 25466.2 25467 Naudé	(5) 4237.49 23592.8 23591 Naudé	(1) 4499.63 22217.8 22218 Eder & Val	(2u) 4681.42 21355.1 21355 Eder & Val
$^4D^3_{3/2}$ 11146	(5) 1654.7 60434 60429 Lyman	(2d) 2247.70 44476.1 44476 Déjardin	(1) 2769.26 36100.1 36098 Naudé	....	(1) 3459.65 28896.4 28890 Stark	(1) 3701.25 27010.2 27014 Eder & Val	(1) 3898.761 25641.9 25641 Stiles	(3) 4035.077 24775.7 24778 Stiles
$^4\bar{P}_{5/2}$ 23451	....	(5) 3107.05 32175.5 32171 Ricard	(10) 4200.76 23798.5 23793 Naudé	(5) 5216.39 19165.0 19169 Naudé	(3) 6029.9 16584 16585 Rasmussen	....	....	....
$^2D^4_{5/2}$ 20360	(0) 1952.6 51216.4 51215 Déjardin	(1) 2835.448 35257.4 35262 Stiles	(1) 3717.85 26889.6 26884 Eder & Val	(1) 4491.603 22257.5 22260 Stiles	....	....	(5) 6089.8 16416 16427 Rasmussen (Blend)	(2d) 6425.1 15564 15564 Rasmussen

TABLE VI.

THE $^2\overline{D}_{3/2}$ SERIES.

n	3	4	5	6	7	8	9	10	11
	73032	57057	48683	43768	40677	38846	37620	36810	36120
$^2D^1_{3/2}$ 100728	(3) 3609.05 27700.4 27696 Naudé	....	....	(1) 1755.4 56967 56960 Lang (Hg ?)	(1) 1665.3 60050 60051 Carroll (Hg ?)	....	(0) 1584.8 63100 63108 Carroll	....	....
$^4D^3_{5/2}$ 14569	....	....	(5) 2930.45 34114.5 34114 Naudé	(1) 3423.751 29199.4 29199 Stiles	(1) 3829.337 26106.8 26108 Stiles	(1) 4117.319 24280.8 24277 Stiles	(4) 4336.89 23051.5 23051 Naudé	(1) 4494.975 22240.9 22241 Stiles	(1) 4638.842 21551.1 21551 Stiles
$^4D^3_{3/2}$ 11146	....	....	(1) 2663.32 37536.1 37537 Naudé	(7) 3064.56 32621.7 32622 Ricard	(15) 3385.25 29531.5 29531 Naudé (Blend)	(3) 3609.05 27700.4 27700 Naudé (Blend)	(1) 3776.259 26473.7 26474 Stiles	(1) 3895.254 25665.0 25666 Stiles	(4) 4003.10 24973.6 24974 Naudé
$^4D^3_{1/2}$ 6370	....	(4) 1973.06 50682.7 50687 Déjardin	....	(3) 2673.19 37397.4 37398 Déjardin	(1d) 2914.52 34300.9 34307 ? Ricard	(1) 3078.42 32474.8 32476 Naudé	....	....	....
$^4\overline{P}_{1/2}$ 21321	(2d) 1933.80 51711.7 51711 Déjardin	(3) 2797.43 35736.6 35736 Naudé (Blend)	....	(2u) 4453.93 22445.8 22447 Eder & Val	....	....	....	....	....
$A(D_2)$ 15014	....	(0) 2378 42039 42043 Déjardin	....	(8) 3476.36 28757.5 28754 Naudé	(1) 3895.905 25660.7 25663 Stiles	....	(2) 4422.03 22607.7 22606 Eder & Val	(1) 4586.92 21795.0 21796 Eder & Val	....

same series are partly explicable as due to differences in the scale and conditions of excitation used by different observers, partly by the inevitable differences in the sensitiveness of photographic plates in different spectral regions, but in part may be real as will be seen on comparing the intensities in the numerous series given by Paschen in the case of neon.[33,34] Such a comparison will leave no doubt as to the reality of the series. The nearness of the term values to one another explains why such full series should be excited. In a similar way complete series are excited in neon while hardly any series can be found in an element like iron. In view of the above results, the arrangement of terms by McLennan, etc., designed so as to show close j-j coupling loses much of its interest. It is true that the doublets and quartets intermingle and the interval rules are not strictly obeyed. Still the several intervals show a striking similarity to the corresponding ones in Cu I where Zeeman effect measurements have made it possible to assign L and S values to the terms. Accordingly, the notation based on Russell-Saunders coupling is retained in the present work. The coupling still approximates to Russell-Saunders type, particularly in the deeper terms.

CALCULATION OF SERIES LIMITS.

A few words may be said about the calculation of the series limits. These series follow approximately a modified Ritz Formula of the type $T = A + \frac{4R}{[n+\alpha+\beta/n^2]^2}$. But the formula does not represent the terms closely enough for the limits to be accurately calculated. For this reason a somewhat new procedure was adopted which was as follows : Having written down the values of all the terms of a series obtained by means of the combination principle, the differences of the consecutive pairs were next written down. The effective quantum number corresponding to each difference was found by linear interpolation from a Rydberg table. The fractional part of each of these effective quantum numbers was then plotted against $1/n^2$ and a straight line was drawn to pass through the maximum number of points. The slope of this line gave β and its intercept on the Y-axis gave α. The modified term values $T^* = \frac{4R}{[n+\alpha+\beta/n^2]^2}$ were then calculated, using these mean values of α and β, and hence a value for $A = T - T^*$ was obtained from each term of the series ; the mean of these values was taken as the most likely value of A. In some of the series the different values of A differed by less than ½%, but in other cases there were differences of the order of 3%. Table VII gives the several values of A thus obtained for each of the series.

TABLE VII.

Series	$^4P_{5/2}$			$^4\bar{D}_{7/2}$		
n	T	T*	A	T	T*	A
3	74239	43135	31104	67069	43135	23934
4	55978	25487	30491	49354	20926	28428
5	47352	16679	30673	42306	13230	29076
6	42361	11719	30642	38714	9327	29387
7	39290	8659	30631	36608	7016	29582
8	37279	6674	30605	35158	5480	29678
9	35890	5289	30601	34090	4407	29683
10	34917	4294	30623	..	..	..
11	34161	3556	30605	..	..	..
12	33624	2993	30631	..	..	..
13	33179	2558	30621	..	..	..

Mean A=30657 Mean A= 29307

Series	$T_{5/2}$			$^2\bar{D}_{5/2}$		
n	T	T*	A	T	T*	A
3	69887	38733	31154	71575	39348	32227
4	58087	24302	33785	55622	23851	31771
5	49892	16258	33634	47244	15805	31439
6	45096	11544	33552	42620	11204	31416
7	42039	8589	33450	40036	8351	31685
8	40017	6629	33388	38160	6449	31711
9	..	..	..	36787	5141	31646
10	..	..	..	35924	4186	31738

Mean A=33562 Mean A=31629

Series	$^2D_{3/2}$			$^4F_{7/2}$		
n	T	T*	A	T	T*	A
3	73032	40064	32968	74356	47497	26859
4	57057	24302	32755	56094	25243	30851
5	48683	16171	32512	48568	16047	32521
6	43768	11419	32349	43809	11201	32608
7	40677	8491	32186	40844	8282	32562
8	38846	6560	32286	38961	6387	32574
9	37620	5209	32411	37635	5075	32560
10	36810	4244	32566	36695	4138	32557
11	36120	3518	32602	36015	3432	32583
12	..	..	..	35425	2897	32528
13	..	..	..	34979	2478	32501

Mean A=32515 Mean A=32555

DISCUSSION OF SERIES LIMITS.

The long series thus obtained make it possible to institute a comparison with Hund's theory. This theory was applied in its original form[35] in *Zs. f. Phys.*, **78**, 541, 1932 but further consideration showed that the results were not in agreement with this theory. According to this earlier theory, all those terms of Hg II that are obtained by adding an electron to some particular term of Hg III must have the latter as their limit. Thus by adding a *p*-electron to the $^3D_3$ term of Hg III we get the terms $^4F_{9/2}$, $^4D_{7/2}$, $^4P_{5/2}$, $^2D_{5/2}$, $^2P_{3/2}$ and $^2F_{7/2}$ of Hg II and hence all these terms should have $^3D_3$ as limit. Similarly the terms $^4F_{7/2}$, $^4D_{5/2}$, $^4P_{3/2}$, $^2D_{3/2}$, $^2P_{1/2}$, $^2F_{5/2}$ resulting from the addition of a *p*-electron to the Hg^{++} ion in the $^3D_2$ state must converge to $^3D_2$. Now since the doublet series of Paschen, which have been used to obtain the absolute values of the terms, are built upon the $d^{10}S_0$ state of Hg^{++}, the common limit of the doublet series from which the term values have been reckoned is the $d^{10}\,{}^1S_0$ term of Hg^{++}. Any other series must follow the ordinary Ritz formula if the values of the terms are calculated from its own proper limit. Let us take the $^4P_{5/2}$ and $^4F_{7/2}$ series as an example. Were the term values measured from the proper limits of these series, which, according to the older theory of Hund, should be $^3D_3$ and $^3D_2$ respectively, the series should obey the Ritz formula. But since the term values are obtained by the combination principle, they are referred to $d^{10}\ {}^1S_0$ as origin. Now the term values of the ${}^4P_{5/2}$ series have to be diminished by 30657 and those of the ${}^4F_{7/2}$ series by 32554 in order that they may follow the Ritz formula ; it follows therefore that the distance of these terms from their limits is less than their distance from $d^{10}\ {}^1S_0$ by 30657 and 32554 respectively. In other words, according to Hund's original theory ${}^3D_3$ and ${}^3D_2$ of Hg III must be deeper than $d^{10}\ {}^1S_0$ by 30657 and 32554 $cm.^{-1}$ respectively. This requires that the ${}^3D_2$ term should be deeper than the ${}^3D_3$ term by about 2000 $cm.^{-1}$ But according to McLennan, McLay and Crawford[11] ${}^3D_3$ is deeper than ${}^3D_2$ by 3179 $cm.^{-1}$ This shows that in reality the ${}^4F_{7/2}$ series has ${}^3D_3$ as limit while the ${}^4P_{5/2}$ series converges to ${}^3D_2$. A similar inversion of series limits has been observed in Cu II and Ag II as also in Au II. In order to explain the anomaly thus observed in Cu II[36, 37] and Ag II[38], Hund revised his theory[39] and showed that it was applicable in its original form only when the limiting terms were erect, *i.e.*, if the term with smaller inner quantum number was the deeper. But when the limit term is inverted—*i.e.*, a term with larger inner quantum number is deeper—the calculation of series limits is to be made by a different method which is as follows: Consider all the terms of a given configuration, which have a given inner quantum number and take all the terms of the ion from which these terms can be obtained by the addition of an electron. Then the deepest of the terms of the first set will have the deepest term of the second set as its limit and so on in order of magnitude. If from a term of the ion more than one term with a given *j* can arise, a corresponding number of series will have that term as limit. The application of these principles to the terms of the configuration $5d^9 6s 6p$ can be carried out in the following manner :—

j	Terms with this j value in order of decreasing magnitude	Term of Hg III from which this j can arise	Assignment of series limits
9/2	$^4F_{9/2}$	$^3D_3$	$^4F_{9/2} \rightarrow {}^3D_3$
7/2	$^4F_{7/2}$; $^4\bar{D}_{7/2}$; $^2F_{7/2}$	$^3D_3$ (two) ; $^3D_2$	$^4F_{7/2} \rightarrow {}^3D_3$; $^4\bar{D}_{7/2} \rightarrow {}^3D_3$; $^2F_{7/2} \rightarrow {}^3D_2$
5/2	$^4F_{5/2}$; $^4\bar{D}_{5/2}$; $^4P_{5/2}$; $^2F_{5/2}$; $^2\bar{D}_{5/2}$	$^3D_3$ (two) ; $^3D_2$ (two) ; $^3D_1$	$^4F_{5/2} \rightarrow {}^3D_3$; $^4\bar{D}_{5/2} \rightarrow {}^3D_3$; $^4P_{5/2} \rightarrow {}^3D_2$; $^2F_{5/2} \rightarrow {}^3D_2$; $^2\bar{D}_{5/2} \rightarrow {}^3D_1$
3/2	$^4F_{3/2}$; $^4\bar{D}_{3/2}$; $^4P_{3/2}$; $^2\bar{D}_{3/2}$; $^2P_{3/2}$	$^3D_3$; $^3D_2$ (two) ; $^3D_1$ (two)	$^4F_{3/2} \rightarrow {}^3D_3$: $^4\bar{D}_{3/2} \rightarrow {}^3D_2$; $^4P_{3/2} \rightarrow {}^3D_2$; $^2\bar{D}_{3/2} \rightarrow {}^3D_1$; $^2P_{3/2} \rightarrow {}^3D_1$.
1/2	$^4\bar{D}_{1/2}$; $^4P_{1/2}$; $^2P_{1/2}$	$^3D_2$; $^3D_1$ (two)	$^4\bar{D}_{1/2} \rightarrow {}^3D_2$; $^4P_{1/2} \rightarrow {}^3D_1$; $^2P_{1/2} \rightarrow {}^3D_1$

The above results are of course the same as those given by Hund in the diagrams appearing in his paper, but the details of the calculation are shown here because Hund has not given such details. It is to be remarked that these results have been obtained on the assumption that the terms are normal in the sense that terms of higher multiplicity are deeper and amongst terms of the same multiplicity those with larger *l*-values are deeper. If we now compare the experimental results with theory we find that the limits of the $^4F_{7/2}$ and $^4P_{5/2}$ series are correctly predicted by the theory as $^3D_3$ and $^3D_2$; but the predictions regarding the $^4D_{7/2}$, $^2D_{5/2}$ and $^2D_{3/2}$ series are at variance with the experimental results. This discrepancy must be due to the fact that the ^2D terms are erect and deeper than ^4D which is contrary to the assumptions made in deducing the theoretical results.

We are now in a position to discuss the series represented by the terms previously designated by T. Since this follows a modified Ritz formula with A=33150, it is clear that its limit is $^3D_3$ and hence it must arise from the addition of a series electron to the configuration $5d^9 6s$ of Hg III. Now since the terms T combine with those of the $5d^9 6s 6p$ configuration and since they must be built upon $5d^9 6s$, they must belong to the configurations $5d^9 6s\,ns$ or $5d^9 6s\,nd$. The magnitude of the terms precludes the latter possibility ; thus they must belong to $5d^9 6s\,ns$ configurations. Since by Pauli's principle $5d^9 6s^2$ can only give rise to ^2D terms, while the terms T, having $j=5/2$ and the limit $^3D_3$, can only be $^4D_{5/2}$, we expect the T-series to begin with the configuration $5d^9 6s 7s$. The term corresponding to this configuration must be of the same order of magnitude as the second member of a series of which the $^2D_{5/2}$ term of the $5d^9 6s^2$ configuration forms the first member. Since the deepest term of this series previously found, *viz.*, 5T did not satisfy this condition, further search was made and two more terms 3T and 4T were found, completing the series. The ^2D terms previously ascribed to the $5d^9 6s 7s$ configuration appear to be higher members of series starting from $5d^9 6s^2\ ^2D_{5/2}$ and the probable intervening members have also been found. These new terms are given in the tables below. The above

4T=58087.

Int.	λ	ν	Comb.	ν Calc.	Observer
3d	7412.8	13487	$^2D_{5/2}$—4T	13488	Rasmussen.
3	6689.6	14945	$^2D_{3/2}$—4T	14945	Do.
10	6146.2	16266	$^4F_{7/2}$—4T	16269	Do.
8	7395.5	13518	4T—$^2F_{7/2}$	13521	Do.

considerations lead to the view that the term given as R^3 by Ricard[16] belongs to the configuration $5d^9 6s7s$ and may be $^4D_{3/2}$.

$3T = 69887.$

Int.	λ	ν	Comb.	ν Calc.	Observer.
2d	6367.5	15700	$3T - {}^4D_{5/2}$	15699	Rasmussen.
8	3948.29	25320.3	$3T - {}^2F_{7/2}$	25321	Naudé.
3	4587.44	21792.6	$3T - {}^4D_{3/2}$	21789	,,
7	3596.68	27795.5	$3T - {}^2P_{3/2}$	27796	,,
1	3269.4	30577.9	$3T - 3^2P_3$	30577	L. & E. Bloch. (E_3?)
1	2154.72	46395.1	$3T - 4^2P_2$?	46402	Déjardin.
1	1837.1	54434	$3T - 5^2P_2$	54436	Lyman.
3	1927.58	51878.5	$3T - 5^2F_4$	51875	Naudé.
4d	7006.9	14268	$3T - 4^2D_{5/2}$	14265	Rasmussen.
3	4415.23	22642.5	$3T - 5^2D_{5/2}$	22643	Eder & Valenta.
1	4689.1	21320.1	$3T - 5^4F_{7/2}$	21319	L. & E. Bloch. (E_3?

Hg II.

$5d^9 6s7s\ {}^2D_{5/2} = 71693.$

Int.	λ	ν	Comb.	ν Calc.	Observer
5	4237.49	23592.8	${}^2D_{5/2} - {}^4D_{3/2}$	23595	Naudé (Blend).
1	4700.33	21269	${}^2D_{5/2} - {}^2F_{5/2}$	21271	,,
2	3772	26503.6	${}^2D_{5/2} - {}^2P_{3/2}$	26499	L. & E. Bloch.
1	3400.4	29399.9	${}^2D_{5/2} - {}^2P_{3/2}$	29402	,,
8	3684.91	27130.0	${}^2D_{5/2} - {}^2F_{7/2}$	27127	Naudé.
3	6220.30	16072.0	${}^2D_{5/2} - 4^2D_{5/2}$	16071	Laffay.
1	4089.237	24447.6	${}^2D_{5/2} - 5^2D_{5/2}$	24449	Stiles.

$5d^9 6s8s\ {}^2D_{5/2} = 56012.$

Int.	λ	ν	Comb.	ν Calc.	Observer
1	5484.6	18228	$3^4F_{7/2} - {}^2D_{5/2}$	18227	L. & E. Bloch.
2	5450.15	18343	$3^4P_{5/2} - {}^2D_{5/2}$	18344	,,
3	9241.6	10819	${}^2D_{5/2} - {}^2P_2$	10818	Rasmussen.
2d	6425.1	15564	$3^2D_{5/2} - {}^2D_{5/2}$	15563	,,

THE SPECTRUM OF DOUBLY IONISED MERCURY.

The study of the series above discussed leads to the conclusion that in the spectrum of Hg III the $d^{10}\ {}^1S_0$ term is higher than $d^9s\ {}^3D_3$ by about 33000 cm.$^{-1}$ When a search was made in the position so indicated it was found that d^{10} $^1S_0$ was 33572 cm.$^{-1}$ above $^3D_3$. Its combinations are given below:

Int.	λ	ν	Comb.	ν Calc.	Observer
6	1994.72	50132.3	$^1S_0—^1P_1$	50132	Déjardin.
0	2369.89	42183.1	$^1S_0—^3P_1$	42184	,,
1	1665.3	60050	$^1S_0—^3D_1$	60054	Carroll.

The intensities are to be compared with those of the corresponding combinations in Cu II[40]:

Comb.	Int.	λ
$^1S_0—^3P_1$	1	1472.48
$^1S_0—^3D_1$	2	1368.00
$^1S_0—^1P_1$	12	1358.84

The lines 1994.72 and 2369.89 thus show relative intensities similar to 1358.84 and 1472.48 and they are ascribed to Hg III by Déjardin. These facts support the classification given above.

Since now we have found that the ground configuration in Hg III is not $5d^{10}$, we are led to institute a comparison with similar spectra so as to find the deepest term. The spectra of Ni I and Pt I show a kindred relationship. Thus in Ni I[6] the d^8s^2 configuration gives the deepest terms. The spectrum of Pt I is also reported by Sommerfeld[41] and Joos[42] to have d^8s^2 as the ground configuration. Probably these authors base their statements on those of Hund[35] who takes as his authority the work of McLennan and McLay.[43] But Livingood,[44] continuing the researches of Haussmann,[45] shows that the ground configuration in Pt I is $5d^96s$. It was thought interesting therefore to find whether the $^3D_3$ term of the $5d^96s^2$ configuration given by McLennan and McLay was the deepest term of Hg III or whether there were deeper terms due to the configuration $5d^86s^2$. The constant frequency differences noted in *Zs. f. Phys.*, **78**, 553, 1932, have enabled the ^3F, ^1D, ^3P and ^1S terms of $5d^86s^2$ to be found and amongst these the $^1S_0$ term is deepest. The terms and their combinations are given in the tables. The following comparison with the spectra of Pt I and Ni I[46] bears out the correctness of the allocation. Thus :—

	Pt I	Ni I	Hg III
$^3F_4$	824	0	—33388
Δ	9293	1332	6073
$^3F_3$	10117	1332	—27315
Δ	5385	884	3050
$^3F_2$	15502	2216	—24265
$^1D_2$	26639		—26880
$^3P_2$	6568		—32980
Δ	11999		5473
$^3P_1$	18567		—27507
$^1S_0$	6140 ($5d^{10}$?)		—34896

It will be seen that the interval separations are similar in the three spectra. Comparing Pt I and Hg III it is also seen that $^1D_2$ is the highest term in the configuration $5d^86s^2$ and the ^3P terms lie amidst the ^3F terms. The $^1S_0$ term in Pt I is ascribed by Livingood to the $5d^{10}$ configuration on the ground that d^8s^2 $^1S_0$ has not been found with certainty in other spectra. But the above comparison shows that the $^1S_0$ term given by Livingood most probably belongs to the $5d^86s^2$ configuration.

$5d^86s^2$ $^3F_4$ = —33388.

Int.	λ	ν	Comb.	ν Calc.	Observer
2	1039.8	96173	$^3F_4$—$^3F_3$	96165	Carroll.
3	921.4	108531	$^3F_4$—$^3F_4$	108531	,,
0	812.9	123016	$^3F_4$—$^1F_3$	123025	,,

$5d^86s^2$ $^3F_3$ = —27315.

Int.	λ	ν	Comb.	ν Calc.	Observer
5	1110.1	90082	$^3F_3$—$^3F_3$	90092	Carroll.
1	976.2	102438	$^3F_3$—$^3F_4$	102458	,,
3	942.7	106078	$^3F_3$—$^3D_3$	106065	,,
1(δ)	855.0	116959	$^3F_3$—$^1F_3$	116952	,,

$5d^86s^2\ {}^3F_2 = -24265.$

Int.	λ	ν	Comb.	ν Calc.	Observer
7	977.1	102344	$^3F_2$—$^3F_2$	102342	Carroll.
3	1148.9	87040	$^3F_2$—$^3F_3$	87042	,,
1	1177.0	84963	$^3F_2$—$^3P_2$	84962	,,
0	1000.5	99950	$^3F_2$—$^3D_2$	99937	,,

$5d^86s^2\ {}^1D_2 = -26880.$

Int.	λ	ν	Comb.	ν Calc.	Observer
3	904.2	110595	$^1D_2$—$^1P_1$	110584	Carroll.
1	974.2	102648	$^1D_2$—$^3P_1$	102636	,,
0	975.0	102564	$^1D_2$—$^3D_2$	102578	,,
1(δ)	1115.5	89646	$^1D_2$—$^3F_3$	89657	,,

$5d^86s^2\ {}^3P_2 = -32980.$

Int.	λ	ν	Comb.	ν Calc.	Observer
1	919.7	108731	$^3P_2$—$^3P_1$	108736	Carroll.
2	856.9	116700	$^3P_2$—$^1P_1$	116684	,,
1	895.1	111719	$^3P_2$—$^3D_3$	111730	,,

$5d^86s^2\ {}^3P_1 = -27507.$

Int.	λ	ν	Comb.	ν Calc.	Observer
4	899.1	111222	$^3P_1$—$^1P_1$	111211	Carroll.
1	968.4	103263	$^3P_1$—$^3P_1$	103263	,,
1	969.2	103178	$^3P_1$—$^3D_2$	103205	,,

$5d^86s^2\ {}^1S_0 = -34896.$

Int.	λ	ν	Comb.	ν Calc.	Observer
3	843.2	118596	$^1S_0$—$^1P_1$	118600	Carroll.
0	903.7	110656	$^1S_0$—$^3P_1$	110652	,,

The fact that $^1S_0$ is the deepest term in Hg III is in agreement with the diamagnetic character of the Hg^{++} ion. The diamagnetic ionic susceptibility can be calculated by Slater's method[47] taking into account the modification introduced by W. R. Angus.[48] Now Angus has calculated the diamagnetic susceptibility on the assumption that $5d^{10}\ {}^1S_0$ is the ground term in Hg III. The value he obtains is 47.57×10^{-6}. If the $5d^8 6s^2\ {}^1S_0$ is taken as the ground state we obtain 54.88×10^{-6}. It is not easy to distinguish between these two values as regards their correctness by comparison with experimental results, since the experimental and calculated values do not show good agreement in any case. Thus we have :—

	Calculated by W. R. Angus	Measured by Kiyoshi Kido[49]
Zn^{++}	15.45	12.8
Cd^{++}	33.94	20.3
Hg^{++}	47.57	36.6

The assumption of Angus that d^{10} is the ground state is correct in the case of Zn^{++} and Cd^{++} , and yet the difference between calculated and observed values increases largely from Zn^{++} to Cd^{++}. But considering the ratio of calculated to observed values, we may expect the calculated value of Hg^{++} to be about $1\frac{1}{2}$ times the experimental value *i.e.*, about 55×10^{-6}. This agrees well with the value deduced above.

A similar calculation indicates that even in Au II $d^8s^2\ {}^1S_0$ is the deepest term. Thus :—

	Calculated by W. R. Angus	Measured by Kiyoshi Kido
Cu^{+}	19.26	16.0
Ag^{+}	42.11	26.2
Au^{+}	58.38	44.8

Here also the assumption of $D^{10}\ {}^1S_0$ as the ground state is correct in the case of Cu^+ and Ag^+. The ratio between observed and calculated values would lead to a calculated value of about 70 for Au^+. If d^8s^2 is taken as the ground configuration we get 70.31 in agreement with this. On the other hand, R. A. Sawyer and Kenneth Thomson[50] consider that λ 1362.44^4, 1224.65^7 and 1166.81^5 represent the combinations of $5d^{10}\ {}^1S_0$ with $^3P_1$, $^1P_1$ and $^3D_1$ respectively and hence deduce that $d^{10}\ {}^1S_0$ in Au II is 15036 cm.$^{-1}$ deeper than $d^9s\ {}^3D_3$. These lines however have not been observed by R. J. Lang[51] who has investigated the same part of the spectrum. This would be explicable if the term belonged to the d^8s^2 configuration, for as pointed out by Livingood the $^1S_0$ term of d^8s^2 is difficult to locate because its combinations are not easily obtained. Besides, if the $\sqrt{\frac{\nu}{R}}$ values of the d^{10} $^1S_0$ term in Pt I, Au II and Hg III are considered, we find that the corresponding Moseley diagram would become a broken line if it is assumed that d^{10} $^1S_0$ is deeper than d^9s $^3D_3$ in Au II while it is higher than $^3D_3$ in Pt I and Hg III. It therefore seems better to assume that d^8s^2 $^1S_0$ represents the ground state of Au^+ also.

The consideration of $\sqrt{\frac{\nu}{R}}$ values led to the investigation of the absolute values of the terms in Hg III. For this purpose second members of the ^3D and ^1D series were sought and found. The terms so discovered are given in the tables.

Hg III.

$5d^97s$ $^3D_3=114201$. ($5d^9$ $6s$ $^3D_3=0$.)

Int.	λ	ν	Comb.	ν Calc.	Observer
2	1944.48	51428	$6p^3F_3—7s^3D_3$	51424	Déjardin.
0	2559.37	39060	$6p^3F_4—7s^3D_3$	39058	,,
1	2767.50	36123	$6p^3F_2—7s^3D_3$	36124	Bloch.
1	2820.01	35451	$6p^3D_3—7s^3D_3$	35451	,,
0	2596.896	24564	$6p^1F_3—7s^3D_3$	24564	Stiles.

$5d^97s$ $^3D_2=115572$.

Int.	λ	ν	Comb.	ν Calc.	Observer
1	1894.06	52796.6	$6p^3F_3—7s^3D_2$	52795	Déjardin.
1	2666.30	37494.0	$6p^3F_2—7s^3D_2$	37495	,,
0	2510.79	39816.1	$6p^3P_1—7s^3D_2$	39816	,,
1	2507	39876	$6p^3D_2—7s^3D_2$	39874	Bloch.

$5d^97s$ $^3D_1=124597$.

Int.	λ	ν	Comb.	ν Calc.	Observer
1	2149.08	46516.8	$6p^3F_2—7s^3D_1$	46520	Déjardin.
0	2044.44	48897.4	$6p^3D_2—7s^3D_1$	48899	,,
1	3227.84	30971.5	$6p^3D_1—7s^3D_1$	30971	L. & E. Bloch.
1	2444.54	40895.1	$6p^1P_1—7s^3D_1$	40893	Déjardin.
1	3042.0	32863.6	$6p^1D_2—7s^3D_1$	32861	L. & E. Bloch.

$5d^9 7s\ ^1D_2 = 127037$.

Int.	λ	ν	Comb.	ν Calc.	Observer
1	2835.95	35301.0	$6p\,^1D_2$—$7s\,^1D_2$	35301	Ricard.
3	2673.19	37397.4	$6p\,^1F_3$—$7s\,^1D_2$	37400	Déjardin.
3	1507.4	66340	$6p\,^3P_2$—$7s\,^1D_2$	66338	Carroll.
0	1556.2	64259	$6p\,^3F_3$—$7s\,^1D_2$	64260	,,
1	2992	33412.7	$6p\,^3D_1$—$7s\,^1D_2$	33411	L. & E. Bloch.

It was found that the $^3D_3$ and $^3D_2$ series converged to a common limit while the $^3D_1$ and $^1D_2$ series converged to a different limit 8800 cm.$^{-1}$ higher. This is also in accordance with Hund's modified theory.[39] The term value of $d^9s\ ^3D_3$ measured from its limit is 213772 so that the ionisation potential $d^9s \rightarrow d^9$ is 26.4 volts. This value is close to what is to be expected from Sommerfeld's[53,54] theory of higher ionisation potentials (*Zs. f. Phys.*, **78**, 283, 1932 and **80**, 415, 1933). As Sommerfeld himself observes[54] his theory correctly represents the variation of the ionisation potential with the atomic number, but the absolute magnitude is not correctly given. But the theory has greater validity the higher the stage of ionisation. The ratio between the ionisation potentials of Ag II and Cu II is 0.863 from experimental data while it is 0.912 from Sommerfeld's theory. The ratio in the case of Cd III and Zn III is 0.832 from observation and 0.897 from theory. The ionisation potential of Hg III calculated according to Sommerfeld's theory from Cd III=25.38 is 23.1 while if calculated from Zn III=30.5 it is 24.9. The value found above, *viz.*, 26.4 volts is to be decreased slightly since it has been obtained by the use of a Rydberg formula which gives too high a value for the limit. According to Russell[58] the correction is $4.5 \times 10^{-5} \times$ length of series per cent.$=1\%$ nearly. The variation of the ionisation potential with Z in the case of Zn, Cd and Hg will then be as follows:—

Zn I	9.35	Zn II	17.88	Zn III	30.5	volts.
Cd I	8.95	Cd II	16.83	Cd III	25.38	
Hg I	10.39	Hg II	18.67	Hg III	26.1	

According to theory the ionisation potential should decrease as Z increases. Hence it will be seen that the theory gives a better representation as the stage of ionisation is advanced. This is also seen in the following:—(See Pauling and Goudsmit, *Structure of Line Spectra*, p. 168, 1930.) The potentials are given in terms of the energy of the 1st hydrogen orbit (*viz.*, 13.53 volts).

B I	0.616	B II	1.787	B III	2.791
Al I	0.440	Al II	1.342	Al III	2.092
Sc I	0.49	Sc II	0.948	Sc III	1.817

The value thus found for the ionisation potential from $d^9s \rightarrow d^9$ leads to an attempt to explain the critical potentials observed by Eldridge and Einsporn. The critical potential of 18 v. observed by Eldridge[54] either corresponds to the production of Hg^{++} from Hg^{+} ions (=18.68 according to Paschen's results) or it may also represent the excitation potential of λ 3984 ($d^9s^2\ ^2D_{5/2}$—$d^{10}p\ ^2P_{3/2}$ according to Paschen) which$=10.39+7.48=17.87$ volts. The other potential, *viz.*, 57 volts may correspond to the ionisation potential of Hg^{++} which is by the above$=10.39+18.68+26.1-4.1=51.1$ volts, or more probably it represents the excitation potential of some Hg IV line. Einsporn[55] gets two critical potentials at 17 and 42 volts respectively. If we assume that the first represents the ionisation potential of Hg^{+} (the ionisation proceeding not from neutral Hg atoms but from singly ionised atoms which may be present in large numbers, *i.e.*, a case of collision with excited or ionised atoms), the second surely corresponds to the production of Hg^{+++} from Hg^{++} ions. The value obtained from the above$=18.68+26.1-4.1=40.7$ volts nearly. The values obtained by Bleakney, however, differ from these results. He finds[56,57] the ionisation potential of Hg^{++} to be $71+2$ volts. If his curves are carefully examined it will be seen that the curve for Hg^{++} shows a change of curvature indicating the possibility of two ways of ionisation. Now Hg^{++} may get ionised according to the scheme $d^8s^2 \rightarrow d^8s$ and the corresponding ionisation potential will be higher than that corresponding to $d^9s \rightarrow d^9$. Thus in Ni I[58], the latter type of ionisation requires 7.62 volts while the former requires 8.65 or 9.30 volts according as the final state in Ni II is one of higher or lower multiplicity. Consequently one has to interpret Bleakney's result by assuming the $d^8s^2 \rightarrow d^8s$ type of ionisation. But since his results do not agree with those of Eldridge or Einsporn, one has to wait for further experimental investigation before a final explanation of his results can be attempted. There is so much diversity among different observers, that even the explanation of the results of Einsporn and Eldridge attempted above is to be considered tentative only. Some other questions raised in this paper, *viz.*, the diamagnetic susceptibilities of Hg^{++} and Au^{+}, the ground term in Au^{+} etc., also require further investigation before a final conclusion regarding them can be reached.

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CYTOLOGICAL AND MORPHOLOGICAL STUDIES IN *LIMNOPHYTON OBTUSIFOLIUM* miq.*

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INTRODUCTION.

Members of Alismaceæ have received very little attention from the cytological view-point. The work of Dahlgren[5] Schaffner[23, 24] and others is only of a morphological nature dealing with the development of embryo sacs and the embryos of many plants of this family.

A preliminary investigation of young anthers and root tips of *Limnophyton* revealed the large size and the small number of the chromosomes which were found to be very favourable for their detailed study in the maturation and somatic divisions. In spite of the voluminous researches in this field, no definite conclusions have yet been established with regard to most of the critical phases in cytological studies.

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It is with a view to observe how far the present researches throw light on these much-discussed problems, this investigation is undertaken.

A study of the somatic chromosomes deserves special attention not only due to the presence of satellites, but also in revealing the telophasic and early prophasic transformations with extraordinary clarity.

HISTORICAL REVIEW.

The family Alismaceæ, though a small one, has attracted the attention of morphologists since the time of Hofmeister[26] whose investigations were directed only towards the general life-history of many plants of this family.

Hofmeister[26] first observed the presence of a Suspensor-haustorium in *Alisma plantago*. Elfving[20] found three-nucleate pollen grains and centrosomes in the embryo sac at the time of fertilisation. Ward[32] studied the development of embryo sac in *Butomus umbellatus* where he observed the T-shaped tetrad and a six-nucleate embryo sac. Schaffner[23] worked out the development of the embryo sac in *Alisma plantago*. He[24] investigated the life-history of *Sagittaria variabilis*, where he reported the presence of two-chambered embryo sac resulting after the first division of the primary endosperm nucleus. In *Limnocharis emarginata*, Hall[11] observed the presence of polyembryony through the division of the pro-embryo. Tischler[26] noted the formation of periplasmodium in some species of Alismaceæ. Dahlgren[5] made a comparative study of five genera of Alismaceæ and found six-nucleate embryo sac in *Alisma*, *Elisma* and *Damasonium* and only five-nucleate embryo sac in *Echinodorus*. Johri[14] studied *Limnophyton obtusifolium* and noted the formation of six-, seven- or eight-nucleate embryo sac, tapetal periplasmodium, male cells or male nuclei in the pollen grain.

From the foregoing résumé it is clear that *Limnophyton* has not been subjected to detailed investigation and the little work that has been done is only carried out from a morphological view-point.

The critical study of somatic mitosis dates back to the work of Baranetzsky[12] whose researches began with various species of *Tradescantia*. Since then, more important contributions are made by Kaufmann,[15] Sharp[30] and Hedayetullah.[12] All these investigators have furnished evidence in support of the view that chromosomes have two distinct morphological constituents—an achromatic substance enclosing two or more chromonemata.

Chromosome constrictions were first noticed by Fraser and Snell[9] and then by a host of other observers such as Newton,[21] Taylor,[31] Sharp[30] and Sakamura.[30] Taylor[31] attached much importance to them in chromosome morphology. They are believed to be of systematic significance by Newton.[21]

The discovery of Satellites or Trabants was made by Nawashin[28] in *Galtonia candicans*. He found them on only one pair of chromosomes, which he designated as the " Satellite chromosomes". He also distinguished between " Leitkorperchen ", a small knob on each chromosome, beyond the spindle-fibre constriction and the actual trabant. Nawashin[28] considered that trabant segments are comparable to the sex chromosomes of insects. Sorokin[28] reported that the satellites were found in the resting nucleus attached to the nucleolus. She concluded that during late prophases the nucleolus divides to form satellite chromosomes. Sanjeninova[28] contradicted Sorokin and said that the nucleolus merely lodges the satellite which is picked up by the chromosome as it is formed.

MATERIALS AND METHODS.

Limnophyton obtusifolium is a rhizomatous aquatic plant partly submerged, the leaves and flowers being aerial. It is about two to four feet high with sagittate leaves and a highly branched cymose scape. The flowers are polygamous with six free perianth lobes in two whorls, six stamens also in two whorls in the staminate flower and an additional apocarpous ovary of 15-20 carpels in the pistillate flower.

The collections were made near Banneraghatta, a village 12 miles off Bangalore. Buds of all sizes were collected on warm sunny days between 11 A.M. and 3-30 P.M. Of the various fixatives tried, Nawashin's solution and Bouin's fluid gave good results. But for root tips Flemming's weak solution was satisfactory.

After the usual process of dehydration, clearing and imbedding, sections were cut at varying thicknesses from 8 to 15 microns for flower buds and from 6 to 8 microns for root tips.

Haidenhein's iron-alum Hæmatoxylin stain was used throughout the investigation and was found to be quite good. The quick process of staining was resorted to, which consists in mordanting the sections in 4 per cent. iron-alum for 2 hours, staining in ½ per cent Hæmatoxylin for the same interval and differentiating in 1 per cent. iron-alum.

SOMATIC MITOSIS.

Anaphase.—It is convenient to begin with this phase as the chromosomes are clearly seen and the changes that take place could be well observed. At the inception of this phase, the chromosomes arch towards the poles, assuming long V-shapes and exhibiting a median constriction in each which serves as the point for the attachment of spindle-fibres and satellites. A pair of satellites is found on every chromosome (Fig. 1).

In the early anaphase, the bases of the V-shaped chromosomes are pointing towards the poles. Gradually, as each chromosome travels towards the pole, it rotates through 180°, so that its apex points towards the pole. In each chromosome it is possible to make out faint achromatic spaces between the chromonemata. The spindle-fibres are hazy at this stage, but gradually become conspicuous as the chromosomes migrate to the poles.

Telophase.—The chromosomes, on reaching the poles, are found to clump, owing to the continued shortening, thickening and approximation. This is the " Tassement Polaire " of Gregoire.[12] Kaufmann[15] and Overton[15] regard it as a fixative artefact. Gradually, the chromosomes relax and separate, during which process inter-chromosomal connections appear.

As the telophasic transformations proceed, the achromatic substance becomes paler and the chromonemata intertwine (Fig. 2). As a result of this, the spaces between the crossing points appear as vacuoles. Then the chromonemata separate and assume a chromomeric appearance accompanied by the formation of chromatic bridges connecting the adjoining chromomeres (Fig. 3). As the chromonemata widen the spaces between them become transparent and appear like a split. Gradually, the nuclear membrane develops immediately followed by the origin of the nucleolus. The end of the telophase is marked by the formation of definite cell plates across the equator.

Interphase and Resting phase.—The usual interphase (Lundegardh[20]) and resting phase exist, the chromosome outline still visible in the former while complete transformations take place in the latter.

Prophase.—Conceding that some of the nuclei are resting, while others are in interphase, the beginning of the prophase is marked by three distinct features, *viz.*, (i) the breaking down of the inter-chromosomal anastomoses, (ii) the approximation of the chromatic threads, and (iii) the change in the shape of the nucleolus.

The chromosome thread shows the chromomeric structure which soon becomes chromonemic. These are then thrown into spirals (Fig. 5) which, after a time, straighten accompanied by condensation. As a result of this condensation and the fading of the achromatic substance, the thread becomes longitudinally split, forming the continuous spireme (Fig. 6).

Transverse segmentation of the spireme takes place with hazy indication of the origin of spindle fibres. Constrictions appear in each segmented chromosome (Fig. 6) and the nucleolus disappears a little later.

Metaphase.—Fully formed chromosomes arrange themselves on the metaphase plate showing distinct longitudinal division in each of them. This is accompanied by the bending of the chromosome at which point two satellites make their appearance. Thus it is clear that the identity of the satellites could be made out from early metaphase up to early telophase.

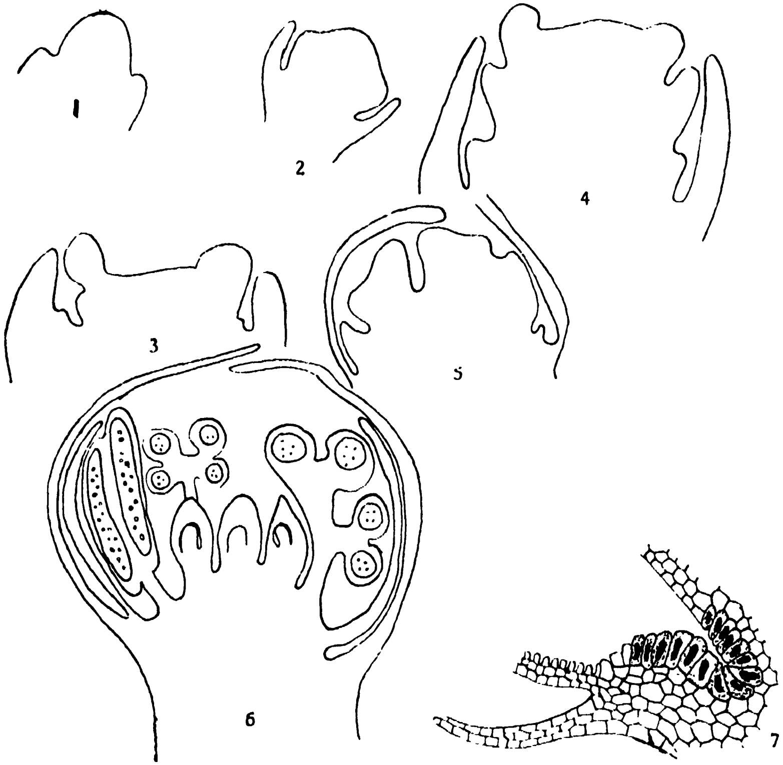
The diploid number of 24 chromosomes has been determined by counting them on early anaphase plate (Fig. 7).

ORGANOGENY.

The primordium of the flower originates as a papillate protrusion a large number of such primordia being enclosed in the axil of a big bract. Very soon the differentiation of the floral parts is noticed. The first whorl to be developed is the calyx (Text-Fig. 1). The sepals make their appearance as minute projections on either side of the floral primordium. Subsequently, the stamens are differentiated. They are in two whorls of three each, the inner whorl (Text-Fig. 2) developing prior to the outer one (Text-Fig. 3). Then the petals are developed in between the sepals and stamens (Text-Fig. 4). Lastly, the gynœcium differentiates in the centre, only in the hermaphrodite flowers (Text-Fig. 6).

MICROSPOROGENESIS AND MALE GAMETOPHYTE.

Microsporangium.—The primordium of the anther very soon gets a rectangular appearance at the corners of which a group of multicellular archesporium is differentiated in the hypodermal region (Fig. 8). Presence of such multicellular archesporia is reported in *Hemerocallis majalis* (Fullmer[3]) and *Mentha aquatica* (Warming[3]). The archesporial cells are prominent from the earliest stages by their conspicuous size, rich cytoplasmic contents and large nuclei. Very soon, the outer layer of the archesporium cuts off a parietal row of cells by a periclinal division. This layer by further division forms



TEXT FIGS. 1-7. Showing the origin of the floral parts in succession and nectariferous cells.

1. Floral primordium with two lateral projections representing sepals. (×200.)
2. Older than above indicating anther primordia. (×200.)
3. Later stage showing in addition to the above outer whorl of stamens and petal primordia. (×200.)
4 & 5. Same as above but advanced in growth.
6. Section of a hermaphrodite flower showing the late differentiation of the gynœcium. (×200.)
7. Conspicuous nectariferous cells situated between the carpels and petals. (×400.)

an endothecium, middle layer and a tapetum (Fig. 9). The middle layer very soon degenerates. The tapetal cells are prominent from the time of their formation until the heterotypic divisions set in. They are uni-nucleate throughout. Their continuity is broken down when the homotypic divisions set in and they are found to be wandering in the locule amidst the pollen grains, gradually becoming disorganised (Fig. 10).

Archesporial mitosis.—While differentiation is taking place in the parietal layers, the sporogenous cells divide a number of times forming the microspore mother cells. A sporogenous cell in metaphase is represented in Fig. 12 (*a*).

Resting Nucleus.—After the mitotic divisions are over, the pollen mother cells pass through a long period of rest during which interval they enlarge (Fig. 13). They are polygonal in outline with a large nucleus practically filling the entire cell. The chromatin is in the form of an irregular network, and the distribution of chromatin is uneven and shows much clumping of the chromatic material where the threads join or cross. The number of nucleoli varies from 4 to 5, which may or may not show any vacuoles or crystalline bodies at this stage. The pollen mother cells will have reached the maximum size before they enter upon the maturation prophase.

Presynizetic Stages.—The onset of the prophase is marked by the dissolution of the inter-chromosomal bands so that some parallelisms between the threads become evident (Fig. 14). The thread which is continuous exhibits thick and thin portions (chromomeric appearance). As the prophase advances, the threads are brought nearer to each other owing to the contraction of the connecting bridges, resulting in a thicker system of threads. By the time the zygotene threads are formed, the nucleoli will have been reduced to one—rarely two—the structure and appearance of which are variable depending upon the fixative used (Fig. 14).

Synizesis.—The first indication of the synizesis is shown by the contraction and tearing away of the delicate chromatin threads, which shrink into a knot abutting on one side of the nuclear membrane. In certain preparations, some highly stained granular bodies are found in the cytoplasm which are comparable to the chromidia—like granules of Digby,[6] the trophoplasmic granules of Mottier[18] or the micro-nucleoli of Coulter.[18] In addition to these granules, some larger bluish spherical bodies are also found, either singly or aggregated in clusters. Similar bodies are figured in *Nephrodium* by Yamanouchi,[34] but he does not make any mention about them (Fig. 15).

Hollow-spireme.—The synizetic knot loosens up by the emergence of a number of loops of comparatively thick threads which may be seen twisting and winding about, but all the while single and continuous. The thread appears to be monili form and slightly double in the material fixed in Bouin's (Fig. 16) but single and homogeneous in the tissues killed in other fluids.

Pachytene.—The commencement of the pachytene is marked by the segmentation of the spireme accompanied by the folding in of the segmented threads. The two arms when they fold may even twist about (Fig. 17).

Diplotene.—The characteristic changes that take place during this stage are the thickening of the threads and the chiasma-formation. Sometimes the twisting arms are so long as to exhibit 7-8 interstitial chiasmata. The diplotene threads show a faint split here and there along the length of each arm in very few cases. This double nature is due to the appearance of the original pre-synizetic split (Farmer and Moore,[8] Sarbadhikari[27]) and is not to be ascribed to the longitudinal division of the pachytene threads (Fig. 18).

Second Contraction.—Some of the diplotene threads contract into a loose knot in the middle, while others are arranged in the form of a number of radiating loops around the central knot. The nucleolus is usually excluded from the knot. These loops are very significant in the formation of the bivalent chromosomes by a process of folding in, thus bringing alternately arranged paternal and maternal chromosomes into a side-by-side position (Fig. 19).

Strepsinema.—As the second contraction loosens, the bivalent segments extricate themselves from the knot at the centre and contract further resulting in the " Strepsinema condition " (Fig. 20).

Diakinesis.—On further condensation of the chromosomes, bivalents are formed, they being accompanied by the separation of the two univalents owing to the complete terminalisation of the chiasmata. The gemini that are thus formed are double and towards late diakinesis they appear in the following forms:—X, Y, O and II,—and are distributed all along the periphery of the nuclear membrane and are of variable lengths (Fig. 21).

Spindle formation and Third Contraction.—Diakinesis is followed by the origin of the spindle fibres from a more or less transparent area surrounding the nuclear membrane. This is comparable to the perikaryoplasm of Lawson,[19] kinoplasmic area of Nothnagel,[19] or perinuclear zone so common in many cases. As spindle fibres grow inwards, the nuclear membrane is disorganised accompanied by the crowding of the gemini towards the centre. This crowded condition of the extremely shortened gemini is known as the " Third contraction " (Nothnagel[19]) (Fig. 22).

Gradually, spindle fibres become abundant and appear to diverge from many points, so that the spindle is multipolar at first (Fig. 22). Later on, it becomes tripolar and ultimately bipolar (Fig. 23). This change in the configuration of the spindle is followed by the separation of the crowded gemini and their rearrangement on the metaphase plate.

Heterotypic Division.—As the bivalents are arranged on the metaphase plate, the mode of spindle fibre attachment on them is clear (Fig. 23). A polar view of the metaphase shows the bivalent number to be twelve (Fig. 24). Some of the bivalents exhibit the tetrad nature.

By the contraction of the spindle fibres the univalents are separated during anaphase and migrate towards the poles. This separation is immediately followed by the origin of a split which becomes startlingly clear all of a sudden. This split is preparatory to the homotypic division to follow soon (Fig. 25). Instances of "Lagging chromosomes" are found (Fig. 26). Darlington[4] and Catcheside[2] are of opinion that the formation of lagging chromosomes is due to the incomplete terminalisation of the chiasmata.

The chromosomes reach the poles and the usual telophasic transformations set in. A broad barrel-shaped phragmoplast is formed and a short interkinesis follows (Fig. 27).

Homotypic Division.—Very soon the spindle formation for the second division is organised in both the daughter nuclei (Fig. 28) resulting in a bilateral tetrad of microspores. Even at this stage the chromidia-like granules are found in the cytoplasm (Fig. 29). The tetrads separate, their angularities round off, accompanied by the differentiation of the wall into exine and intine, the former showing 4—5 germinal spots. The pollen grains lie free in the locule interspersed with the disorganising phagocytic uni-nucleate, wandering tapetal cells (Fig. 10).

Male Gametophyte.—The gametophytic divisions set in early. A polar view of the metaphase plate shows 12 chromosomes (haploid number) with a terminal satellite on each of them (Fig. 30). At the telophase, the phragmoplast is very broad with an evanescent cell plate. Two nuclei are thus formed, the larger constitutes the tube nucleus and the smaller a generative nucleus. The second gametophytic division quickly follows the first. The spindle is narrow and elongated with no trace of a cell plate (Fig. 31). Two generative nuclei are formed, each being surrounded by a distinct hyaline cytoplasmic sheath which imparts a cell-like appearance. The nucleus of each male cell is spherical in the beginning, but gradually becomes drawn out and spindle-shaped (Figs. 32 and 11). The dehiscence of the anther is effected as usual by the action of the endothecium. Special stomium cells are not found.

MEGASPOROGENESIS AND FEMALE GAMETOPHYTE.

The carpels, 15—20 in number, arise as protuberances all over the slightly convex receptacle. At the base of the flower between the carpels and petals are found conspicuous nectariferous cells with rich contents and amœboid nuclei (Text-Fig. 7). They become conspicuous just before the fully-developed embryo sac is formed and disorganise after pollination.

After the nucellar primordium has developed from the placental tissue, the two integuments originate and grow over the nucellus in quick succession, the ovule, as a whole, assuming anatropous condition. Along with the differentiation of the integuments, the differentiation of the uni-cellular archesporium is visible in the hypodermal regions of the nucellus. It can be easily recognised by its large size, richness of cytoplasmic contents and prominent nucleus. This hypodermal initial functions directly as the megaspore mother cell without cutting off any parietal cells.

The megaspore mother cell undergoes the usual meiotic divisions which have been described in detail elsewhere in connection with microsporogenesis (Fig. 33). After the heterotypic division is over, two megaspores are formed of which the chalazal one develops (Fig. 34). The second mitotic division follows accompanied by the enlargement of the embryo sac in both directions. The micropylar end gradually dilates while the antipodal end tapers and bends towards the funiculus. The nucleus at the chalazal end of the embryo sac is very much smaller when compared with the remaining three nuclei, thus already forecasting the ephemeral nature of the antipodals (Fig. 36).

Third mitotic division takes place, the smaller nucleus lagging behind. Later on, that too divides and ultimately the 8-nucleate condition is reached (Fig. 37).

The organisation of the embryo sac soon follows (Fig. 38*a*). The two synergids are the first to be differentiated. They are vacuolate at their broader basal end with a definite cell-membrane, while their apical part is accompanied by a "Filiform Apparatus" of Schacht. he conical apex of each synergid is traversed by a number of striations. Alternating with these striations are found longitudinal spaces and a somewhat hyaline area could be made out at the apex of each synergid during later stages (Fig. 38*b*). These striations are considered to be minute canals through which proteid and glucose flow out and exert a chæmotropic stimulus on the pollen tube (Ishikawa[13]).

The egg is large and is situated between the two synergids. The cytoplasm of the egg is slightly vacuolate and a delicate plasma membrane surrounds it without having any definite cell-wall. Sometimes the egg has a beak-like projection pointing downwards (Fig. 46).

The two polar nuclei migrate towards the centre of the embryo sac, where they approximate but do not fuse soon. It is always seen that the micropylar nucleus is larger than the antipodal one (Fig. 39). There is usually one—rarely two—antipodal nucleus persisting till the complete organisation of the embryo sac.

FERTILISATION.

Pollination is effected by the agency of wind or insects. The time elapsing between pollination and fertilisation is very rapid as can be inferred from the quick growth of the pollen tube which was not possible to be traced. Similar instances have been recorded in the allied genera, *Sagittaria* (Schaffner[24]) and *Limnocharis* (Hall[11]), where the estimated time is about 8 to 10 hours.

As the pollen tube enters, the embryo sac through the micropyle, it disorganises one of the synergids while the other persists for a long time, until as late as 2 to 3-celled embryo forms. Gradually the tip of the tube swells, curves inwards and approaches the egg. The contents are discharged which include two male nuclei, remnant of the tube nucleus and a certain amount of cytoplasm (Fig. 41).

Syngamy.—As soon as the male nucleus comes in contact with the egg, the nuclear membranes of both break down and the contents resolve into reticulate structures, the karyotin of the male nucleus being more deeply stained than that of the egg. In this condition syngamy is effected (Fig. 42).

Polar Fusion.—Polar fusion takes place a little prior to or later than syngamy, but always after the entry of the pollen tube into the embryo sac. Prior to fusion, the nuclear membranes of both the polar neclei disintegrate, the contents resolve into spiremes with one nucleolus in each and the fusion is brought about (Fig. 43).

Triple Fusion.—This is a very slow process when compared to syngamy and usually takes place when the embryo is in a 2-celled stage. The triple fusion is effected when the nuclear contents are in a spireme condition, the spireme of the fusion-nucleus being faintly stained, while that of the second male nucleus is more chromatic and slightly reticulate (Fig. 44).

ENDOSPERM.

After triple fusion is over, the primary endosperm nucleus migrates towards the base of the embryo sac where it divides transversely. The wall extends on either side of the embryo sac completely, thus dividing it into a large micropylar chamber and a small antipodal one (Fig. 47).

The nucleus of the smaller chamber divides usually once, sometimes one of them dividing again, thus forming 2 or 3 nuclei (Fig. 51). They gradually enlarge as they absorb nutrition from the chalazal end, thus the lower chamber as a whole serving as an incipient haustorium. The nucleus of the micropylar chamber migrates again upwards where it undergoes a series of divisions. The resulting nuclei are shifted to the peripheral portions of the sac accompanied by wall-formation. No free nuclei are found excepting a few in the central region. As the embryo development proceeds, almost all the endosperm is used up except for a thin membranous portion in the periphery (Fig. 54).

EMBRYOGENY.

The embryo development is very precocious. The fertilised egg divides by a transverse wall without passing through any period of rest, which is rather unusual. The basal cell becomes large and vescicular while the terminal cell divides again thus forming a pro-embryo of three cells. The embryonal differentiation does not commence at this stage as is reported in *Sagittaria* (Schaffner[24]) and allied genera, but two more divisions occur forming a pro-embryo of 5 cells (Fig. 49). The first longitudinal wall is then observed in the terminal cell, the plane of division being at right angles to the sagittal plane of the ovule. The next division in the terminal cell is also longitudinal, but at right angles to the original plane ; thus it forms a quadrant (Fig. 50). Similar divisions are set up in the penultimate cell of the pro-embryo, the wall-formations being identical with the last. The divisions gradually proceed towards the base of the embryo. So the embryo formation takes place in basi-petal succession. By further divisions, except in the basal cell, an embryonal mass is formed.

Periclinal division starts from the side where the stem tip is to be differentiated and gradually proceeds towards the other side till the very base. This layer forms the dermatogen (Fig. 53). At this stage, a protrusion is visible on one side, marking the base of the cotyledon. Just below this is a notch where the lateral stem tip is differentiated later.

A ripe embryo was observed by taking a free-hand section of the seed owing to the difficulty experienced in cutting through the sclerenchymatous integuments. In a mature condition the embryo is bent like a horse-shoe and almost fills the cavity of the seed except for a thin layer of endosperm surrounding it. It has a large massive terminal cotyledon occupying half of its bulk ; a lateral stem tip situated in a pouch at the bend.

ABNORMALITIES.

(i) *Generative Nuclear Fragmentation.*—One of the two male nuclei in the pollen tube is seen in a fragmenting condition just after entry into the embryo sac and lying in proximity with the egg (Fig. 40).

(ii) *Aberrant Triple Fusion.*—In one case it is noticed that while the polar nuclei are migrating towards the centre of the embryo sac, a sperm nucleus is seen perching on each one of them. Correlating this with the equally rare case of generative nuclear fragmentation, it is suggestive that each of the fragmented bits might fuse independently with the two polars (Fig. 45).

(iii) In a third case, the pollen tube is seen to have entered the embryo sac and lying in the vicinity of the egg. The tip of the pollen tube appears to be broken, but the two sperm nuclei and much of the cytoplasmic contents are still *in situ.* In the centre of the embryo sac triple fusion is observed by the two notches that are visible on the nuclear complex. This evidently suggests that the triple fusion is being effected by an extra sperm nucleus (Fig. 46).

A similar case is reported in *Oenothera biennis* by Ishikawa[13] who observed one male nucleus fusing with the egg, the other still in the pollen tube and a third effecting triple fusion. He assigned the following two reasons for such an unusual phenomenon, *viz.* :—(i) entry of more than one pollen tube into the embryo sac, the fourth male nucleus not being traced, and (ii) the formation of three sperm nuclei in the pollen tube.

DISCUSSION.

Somatic Mitosis.—In a study of the somatic mitosis the nature of chromosomes during the various stages and the time of splitting up of the chromosomes are the controversial points. The present investigation shows the chromomeric condition to be characteristic of near-resting nucleus and the early stages of the prophase. Gradually, by the coalescence of the chromomeres, a continuous chromonema is formed which characterises the chromosomes from late prophase up to early telophase. This view is also expressed by Kauffmann[15] and Gates.[10]

The telophasic transformations take place by the formation of inter-twining chromonemata and median vacuolisation as is held by Hedayetullah[12] and others. But the other view of the Gregoirean school, which explains these changes to take place in an irregular alveolar manner, does not appear to hold good in the present case.

Lateral anastomoses between the chromosomes in the early telophase have evoked much discussion. The school led by Farmer,[8] Gates,[10] Sarbadhikari[27] and others explain them as a form of pseudopodial outgrowths from the chromosomes, while Gregoire,[12] Sharp[30] and others describe them as adhering portions of the chromosomes which were closely pressed together during 'Tassement polaire'. The latter view seems to be tenable in the present case.

Regarding the time of longitudinal splitting of the chromosomes, different opinions are put forward. Kauffmann,[15] Newton,[21] Sharp[30] and others observe that this division is initiated in the mid-prophase, while certain others like Digby,[6] Sarbadhikari[27] and Gates[10] defer it to late prophase just before the arrangement of the chromosomes on the metaphase plate. The present observations are in conformity with the former view.

Satellites are regarded as mere chromatic swellings on the chromosomes which are clearly visible during metaphase and anaphase in somatic mitosis and are masked during telophase and early prophase. Some authors (Smith[28]) are of opinion that during this obscurity, the satellites are found to be attached to the nucleolus which is better seen in the meiotic studies than in mitoses (Sorokin[28]). But in the present investigation, the satellites are not observed in meiotic studies, but in mitoses their origin is clearly seen at the middle portion of each chromosome during late prophase, as small swellings. Any connection between them and the nucleolus is not noticed.

The presence of chromosome constrictions is a characteristic feature of meiotic as well as mitotic chromosomes of the plant under investigation. In somatic chromosomes they are found to be more conspicuous than in meiosis.

Nucleolus.—The structure and function of the nucleolus have evoked much controversy from a long time. Since the time of Strasburger,[10] an important rôle is attributed to it of contributing to the formation of chromatin material, achromatic figure or otherwise. Wager[10] and Latter[16] observed the exchange of material between the chromatin and nucleolus. Darlington[4] contradicts the presence of any connection between the nucleolus and the chromatin as being antagonistic to the theory of chromosome individuality.

In *Limnophyton*, the author has observed that the structure, inclusions such as vacuoles and crystals, staining capacity of the nucleolus and its association with the spireme thread are all variable in the extreme, depending upon the fixatives and therefore attaches a very insignificant rôle to the nucleolus.

Periplasmodium formation.—This is a common feature of most of the monocotyledonous families such as Alismaceæ, Commelinaceæ, Aroideæ (Schurhoff[26]).

The mode of periplasmodium formation in the present case is somewhat distinctive. In *Lemna*, Caldwell[3] observed periplasmodium which is somewhat analogous to the present case. Wandering tapetal cells have been reported in *Arisæma* (Mottier[17]). In *Limnophyton* the tapetal cells break down after the heterotypic division in the microspore mother cells, lose their cell-walls and are found as phagocytic uni-nucleate wandering cells. In the same plant, Johri[14] has reported the formation of a true periplasmodium.

Male Cells.—The presence of male cells in the angiospermous pollen grains is a much-debated question. They are said to be of common occurrence by Gager[33], Welsford[33], Ishikawa[13] and Finn[7]. In *Limnophyton*, the male cells are easily recognisable in fully developed pollen grains by their hyaline cytoplasmic sheaths, surrounding the vermiform nuclei, while the general cytoplasm of the pollen grains is somewhat denser. But Johri[14] reports the occurrence of male cells or male nuclei.

Embryo Sac.—The formation of embryo sac in the Alismaceæ is a much-debated question. Most of the earlier authorities like Schaffner[24] and Cook[26] report a normal eight-nucleate embryo sac in *Sagittaria* and *Alisma*. More recent work of Dahlgren[5] who has investigated five genera of this family finds that six-nucleate embryo sac is common in most of them and that it is even five-nucleate in *Echinodorus*. Johri[14] has reported that the number of nuclei in the embryo sac of *Limnophyton* is predominantly six, though seven or eight nuclei are sometimes seen. The present author finds, however, that a normal eight-nucleate embryo sac is formed in which one or two nuclei degenerate very soon, thus appearing as six- or seven-nucleate embryo sac.

This case is very much analogous to the development of oogonium in Fucales. In *Fucus*, the oogonium initial by three successive divisions forms 8 nuclei where all of them develop into eggs. In *Ascophyllum*, only four of the eight nuclei organise into eggs, the remaining four degenerate. In *Pelvetia* two eggs and in *Himanthalia* only one egg develops.[14] What is applicable to the different genera of Fucales is possible in the case of *Limnophyton*.

Fertilisation.—The time elapsing between pollination and fertilisation is highly variable. In *Lilium* (Nothnagel[20]) and *Limnocharis* (Hall[11]) the interval is estimated to be from 8 to 10 hours. The condition of the male and female nuclei at the time of fusion also differs in different cases. In *Lilium philadelphicum* (Nothnagel[20]) it is seen to take place in a spireme condition. It is also possible that the same species might show variation in the structure of the male and female nuclei at the time of fusion, as in *Fritillaria* (Coulter and Chamberlain[3]). In *Limnophyton* the whole process takes place very rapidly probably in the course of 8—10 hours. At the time of syngamy the male and female nuclei resolve into reticulate structures by the disorganisation of their plasma membrane, the reticulum of the male nucleus being more deeply stained than that of the egg. Syngamy takes place in this condition.

Triple fusion is a much-delayed process. Even during this fusion, the chromaticity of the male nucleus is greater than that of the polar fusion nucleus, the fusion being effected in a spireme condition. Such a delayed triple fusion is recorded in *Elodea* (Wylie[20]). This aspect is of special interest and will form a separate paper to be published later.

Endosperm.—The endosperm formation in *Limnophyton* is peculiar in that it sets apart a small chamber at the chalazal end for a different purpose while the endosperm formation takes place only in the micropylar chamber which is very large. This is a feature which it shares along with many other members of Helobiales (Coulter and Chamberlain[3]). The nucleus of the smaller chamber divides to form 2 or 3 nuclei and the chamber as a whole assumes a haustorial rôle. This haustorium is of a simple type and is comparable to the 'basal apparatus' of *Thismia* (Pfeiffer[22]). In *Xyris indica* (Schuroff[20]) a similar small chamber is formed containing 20—30 nuclei, which also serves as an incipient haustorium.

Embryogeny.—The embryogeny of *Limnophyton* corresponds to Alisma type which is regarded to be the most primitive among the four types of monocotyledonous embryos by Coulter and Chamberlain.[3] Its main features are an undividing enlarged basal cell and a pro-embryo of 4 cells which differentiates in basi-petal succession having a large terminal cotyledon and a lateral stem tip.

SUMMARY.

1. In a study of the somatic mitosis, early-anaphase chromosomes are seen to have a pair of satellites on each of them and exhibit chromatic and achromatic substances. During

early telophase, the polar clumping takes place after recovery from which the chromosomes exhibit chromomeric appearance which gradually becomes chromonemic as the resting stage is approached.

2. At the onset of the next prophase, the chromomeric condition reappears and the splitting of the chromosomes takes place during mid-prophase. By this time, the two satellites appear at the bend of each chromosome.

3. The cytology of the pollen mother cells shows the occurrence of second and third contraction stages and the presence of chromosome constrictions.

4. The bivalent number of 12 chromosomes are counted on the metaphase plate.

5. By successive homotypic divisions, a bilateral tetrad of microspores is formed.

6. Gametophytic divisions in the pollen grains set in while they are in the anther locule, each pollen grain containing 3 nuclei. Of these, two are organised into spindle-shaped male cells.

7. Wandering tapetal cells are found in the anther locule while gametophytic divisions are taking place.

8. In megasporogenesis the hypodermal archesporium directly functions as the megaspore mother cell which divides to form a dyad of megaspores, of which the chalazal one developes.

9. Three successive divisions in the latter result in the formation of a normal 8-nucleate embryo sac in which one or two of the antipodal nuclei may soon disorganise.

10. After syngamy, the fertilised egg divides without any period of rest, very often before the formation of the primary endosperm nucleus.

11. The first division of the endosperm nucleus results in a two-chambered embryo sac, the smaller antipodal one assuming a haustorial rôle, while the upper larger one contains the embryo.

12. The mature embryo which belongs to Alisma type is bent like a horse-shoe with a terminal cotyledon and a lateral stem tip with practically no endosperm around.

In conclusion, I wish to express my deep sense of gratitude to Dr. M. A. Sampathkumaran, M.A., Ph.D., under whose able direction the investigation was carried out.

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EXPLANATION OF FIGURES.

All the figures (except Fig. No. 54) were drawn with the aid of an Abbe Camera Lucida. Since different optical combinations were used, the magnification is given against each figure.

FIG. 1. Early Anaphase showing V-shaped chromosomes migrating to poles. Two satellites are observed at the bend of each chromosome. (×2700.)

FIG. 2. Early Telophase showing intertwining chromonemata and lateral anastomoses between the chromosomes. (×1800.)

FIG. 3. Late Telophase showing chromomeric structure of the chromonemata. (×1800.)

FIG. 4. Interphase. (×1800.)

FIG. 5. Mid-prophase showing gradual straightening of the spirally coiled chromonemata. (×1800.)

FIG. 6. Late prophase showing segmented spireme. (×1800.)

FIG. 7. Polar view of metaphase plate showing the diploid number of 24 chromosomes.

FIG. 8. Section of an young anther with hypodermal multicellular archesporium. (×400.)

FIG. 9. Four-layered wall of the anther locule (outer exothecium, next endothecium, middle layer and tapetum) and microspore mother cells. (×400.)

FIG. 10. Three-nucleate pollen grains interspersed with wandering tapetal cells. (×400.)

FIG. 11. Ripe pollen grain with two male cells and one tube nucleus in each. (×400.)

FIG. 12. An archesporial cell of the anther in metaphase. (×1800.)

FIG. 12*a*. One chromosome from above magnified showing two satellites. (×1800.)

FIG. 13. Resting microspore mother cell. (×1800.)

FIG. 14. Tangential section of a microspore mother cell in Zygotene stage showing parallelisms. (×1800.)

FIG. 15. Pollen mother cell in Synizesis; presence of granular and spherical bodies in cytoplasm. (×1800.)

FIG. 16. Pollen mother cell in open spireme. (×1800.)

FIG. 17. Pachytene stage; segmented spireme looping in. (×1800.)

FIG. 18. Late Diplotene; interstitial chiasmata are visible. (×1800.)

FIG. 19. Second Contraction; vacuoles observed in the nucleolus. (×1800.)

FIG. 20. Early Strepsinema. (×1800.)

FIG. 21. Diakinesis; Gemini of variable lengths and disposition. (×1800.)

FIG. 22. Third Contraction stage and multipolar spindle. (×1800.)

FIG. 23. Heterotypic metaphase. (×1800.)

FIG. 24. Twelve Bivalents (haploid number) counted from the polar view of the metaphase. (×1800.)

FIG. 25. Heterotypic anaphase. (×1800.)

FIG. 26. Late Anaphase with one lagging chromosome stretched along the spindle. (×1800.)

FIG. 27. Late Telophase with broad phragmoplast in the centre. (×1800.)

FIG. 28. Homotypic metaphase in the daughter nuclei. (×1200.)

FIG. 29. Bilateral tetrad of microspores still enclosed in the mother cell wall; chromidia-like granules visible in the cytoplasm. (×1200.)

FIG. 30. First gametophytic division in the pollen grain; polar view of the metaphase plate showing the haploid number of 12 chromosomes each bearing a satellite. (×1200.)

FIG. 31. Second gametophytic division; early telophase. (×1200.)

FIG. 32. Three-nucleate pollen grain with one tube nucleus and two male cells. (×1200.)

FIG. 33. Megaspore mother cell in Diakinesis. (×900.)

FIG. 34. A dyad of megaspores of which the micropylar disintegrating and the chalazal one in late telophase (homotypic). (×900.)

FIG. 35. Two-nucleate embryo sac. (×900.)

FIG. 36. Four-nucleate embryo sac in which one of the chalazal nuclei is smaller. (×900.)

FIG. 37. Eight-nucleate embryo sac before organisation. (×900.)

FIG. 38. Organised embryo sac with egg apparatus, two polar nuclei and one persisting antipodal nucleus (the other two already disorganised). (×900.)

FIG. 38*a*. The synergids magnified each showing the filiform apparatus at the pointed end, nucleus and cytoplasm in the middle and a large vacuole at the broader end. (×1200.)

FIG. 39. Embryo sac showing the pollen tube in the vicinity of the egg; the polar nuclei approximated. (×900.)

FIG. 40. Generative nuclear fragmentation in the pollen tube. (×900.)

FIG. 41. The contents of the pollen tube being discharged (on the extreme left). (×1200.)

FIG. 42. Syngamy, the karyotin of the male nucleus being more chromatic than that of the egg. (×1200.)

FIG. 43. Polar fusion in a spireme condition. (×1200.)

FIG. 44. Triple fusion. (×1200.)

FIG. 45. Abnormal triple fusion; two male nuclei are seen, each in contact with a polar nucleus. (×900.)

FIG. 46. Another abnormal triple fusion; two male nuclei in the pollen tube, and a third one fusing with the primary fusion nucleus. (×1200.)

Fig. 47. Two-chambered embryo sac with a big micropylar chamber and a small antipodal one. (×900.)

Fig. 48. Two-celled embryo; two endosperm nuclei found in the micropylar chamber. (×240.)

Fig. 49. Four-celled pro-embryo, the basal cell being large and vescicular. (×800.)

Fig. 50. Quadrant stage in the terminal region of the embryonal mass. (×900.)

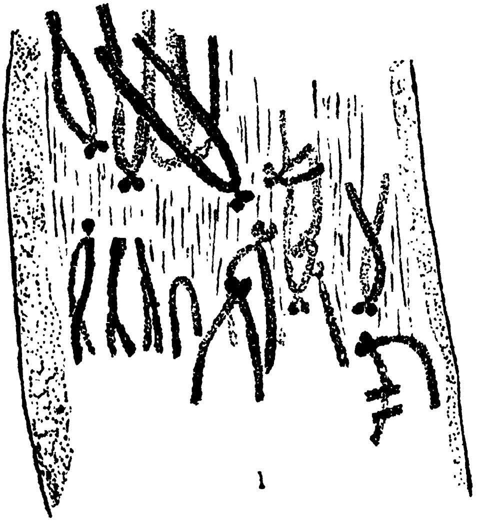
Fig. 51. The smaller antipodal chamber with two large nuclei (haustorial in function). (×900.)

Fig. 52. Embryonal mass enlarged by further division in all the cells. (×900.)

Fig. 53. Formation of dermatogen by the periclinal division; the projecting tissue on the right marks the base of the cotyledon. In the depression below the lateral stem tip is to be formed later. (×900.)

Fig. 54. A free-hand section of the mature seed showing a fully developed embryo with a massive terminal cotyledon and the lateral stem tip contained in the pouch at the bend. (×25 approx.)

PLATE I



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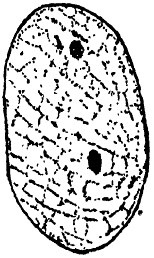

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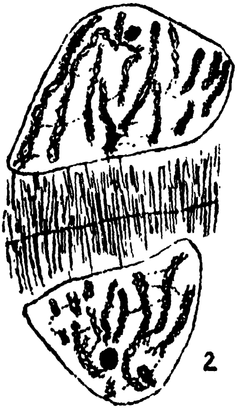

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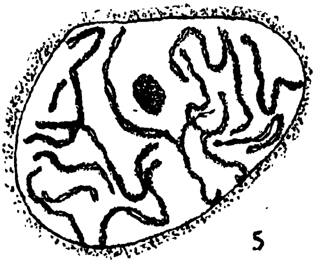

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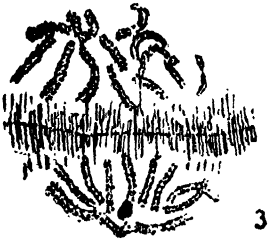

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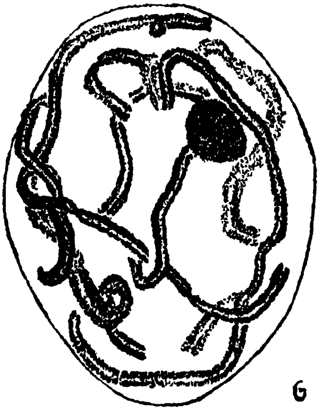

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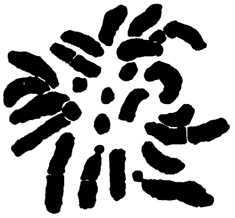

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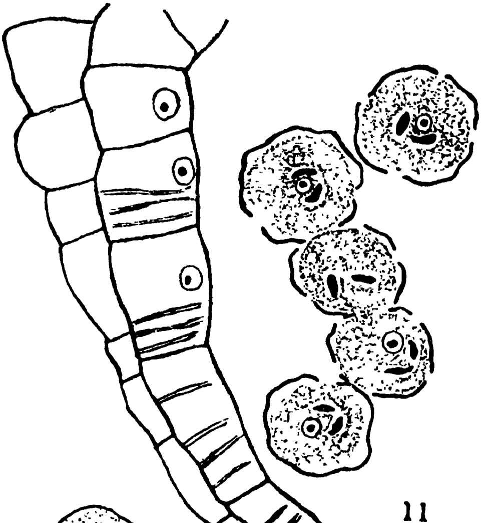

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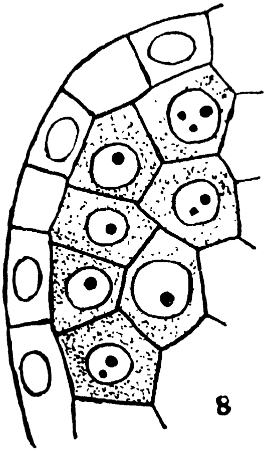

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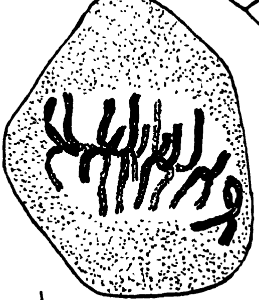

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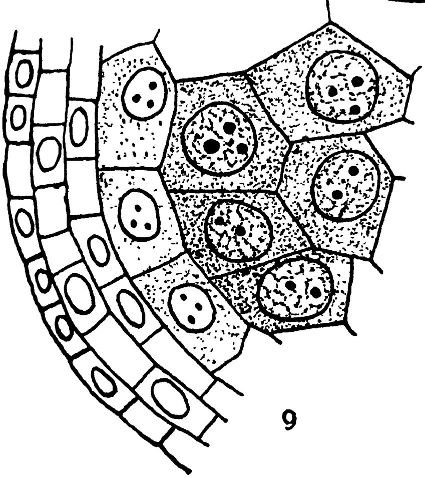

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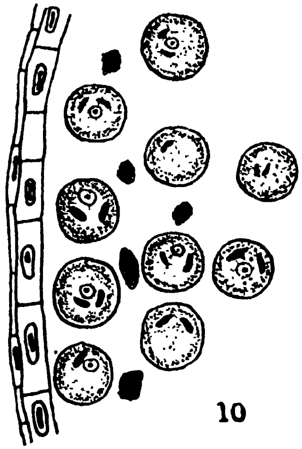

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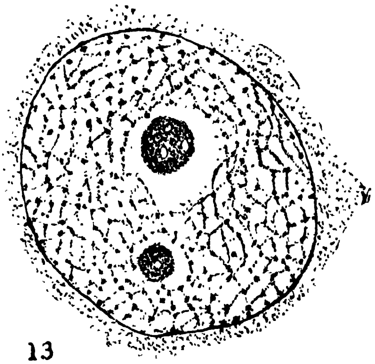

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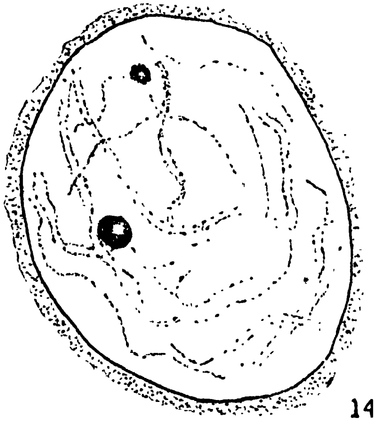

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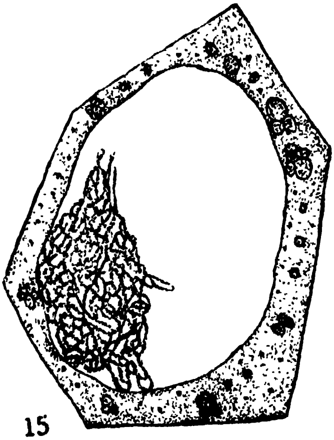

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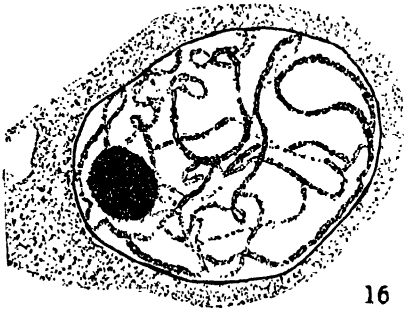

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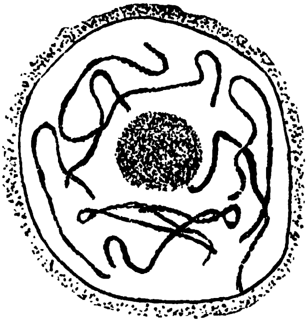

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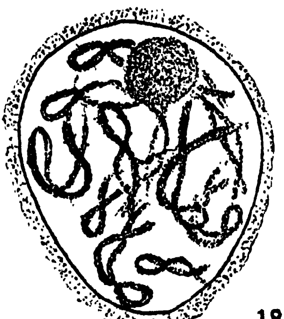

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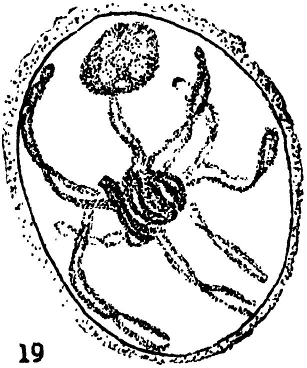

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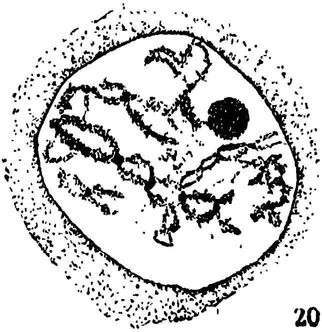

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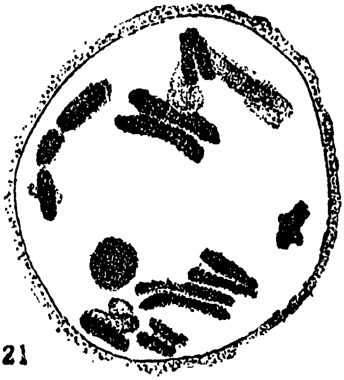

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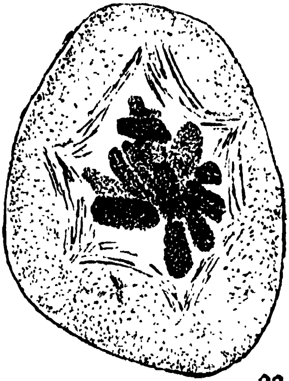

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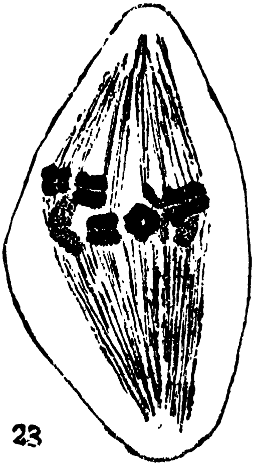

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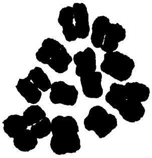

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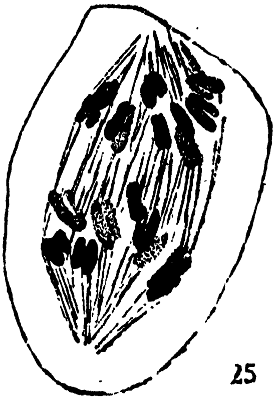

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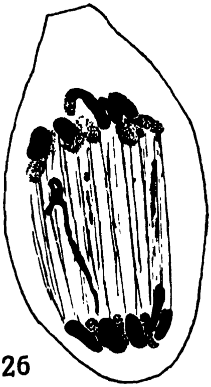
PLATE V



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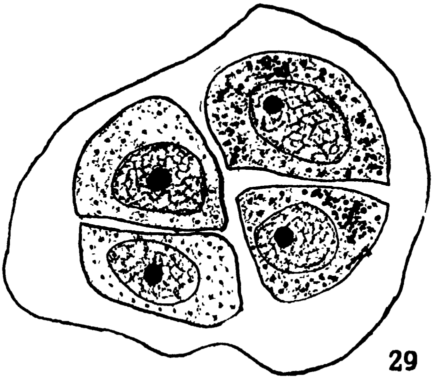

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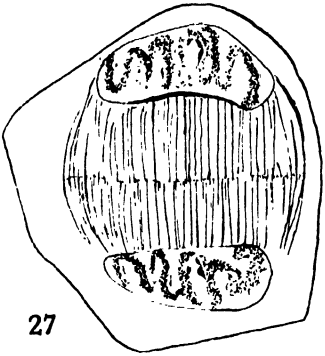

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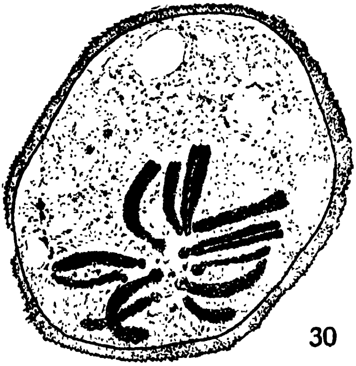

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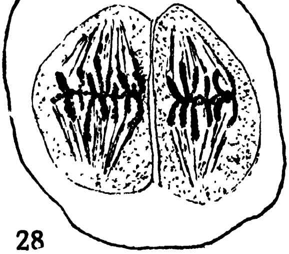

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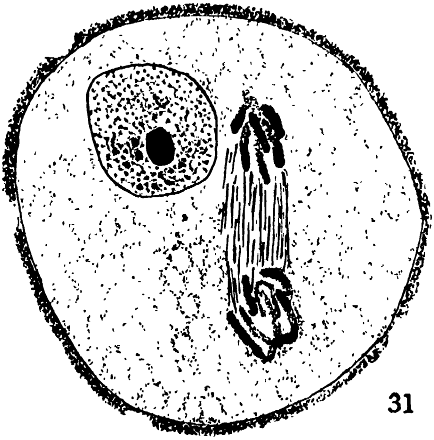

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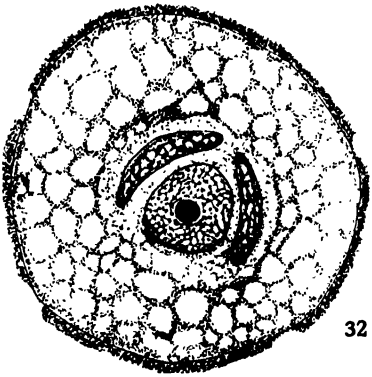
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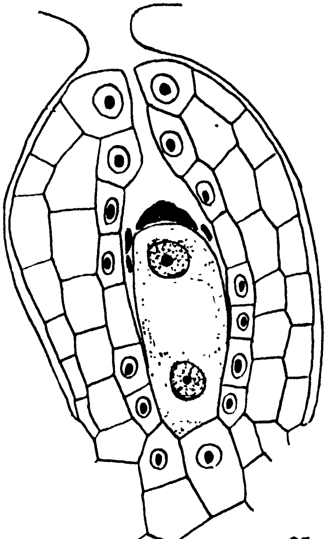
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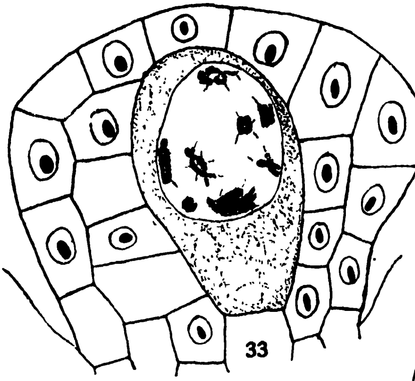
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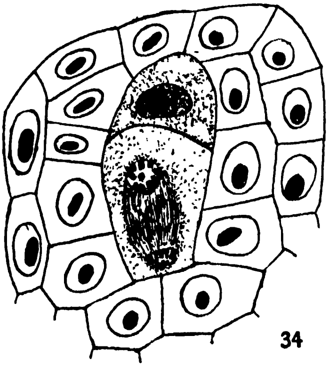
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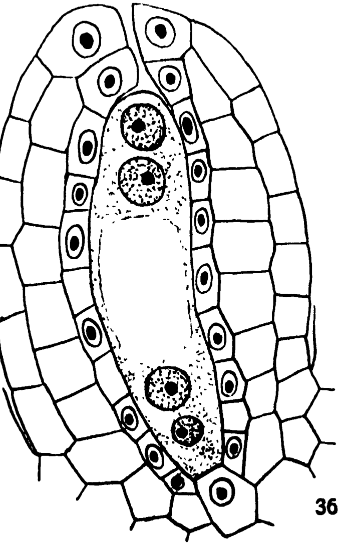
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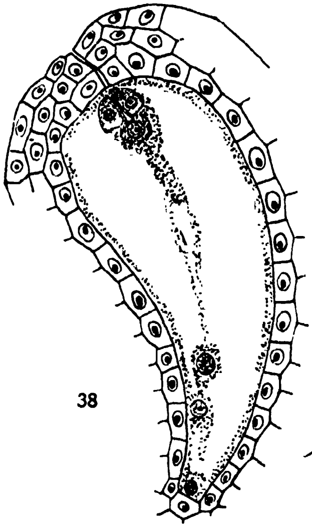

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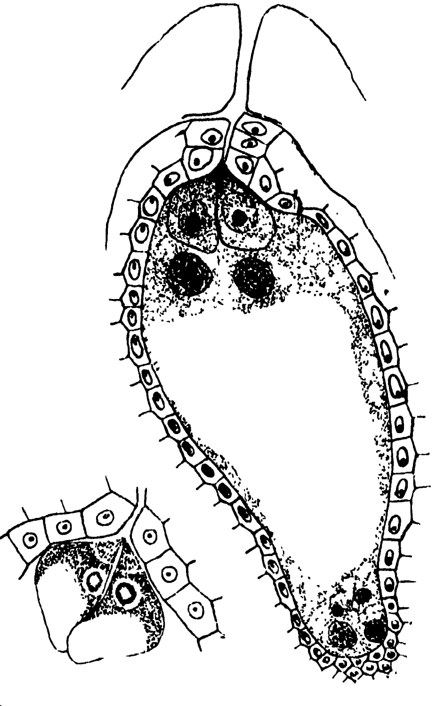

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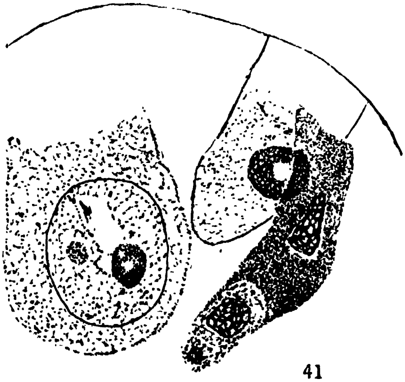

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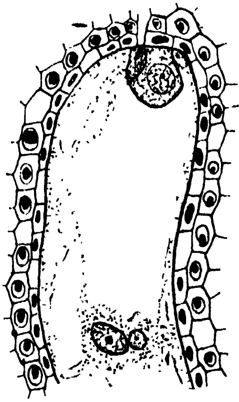

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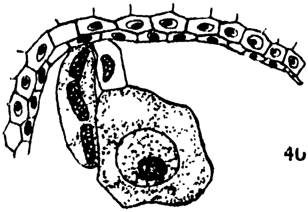

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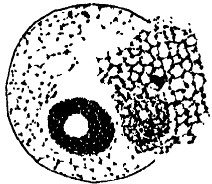

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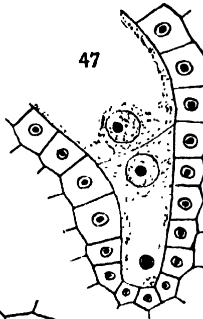

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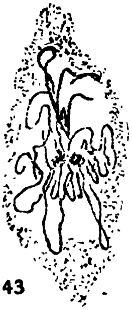

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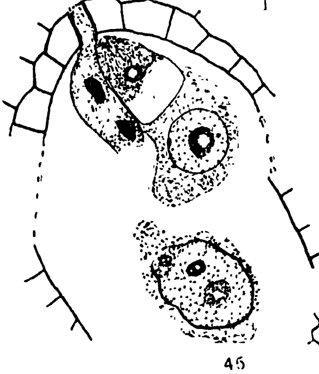

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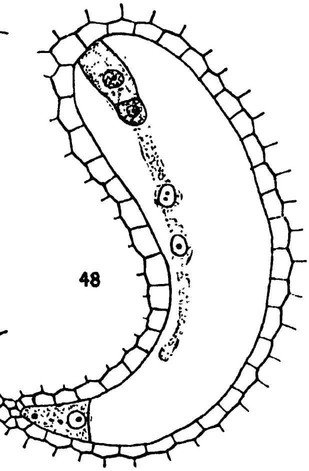

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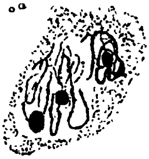

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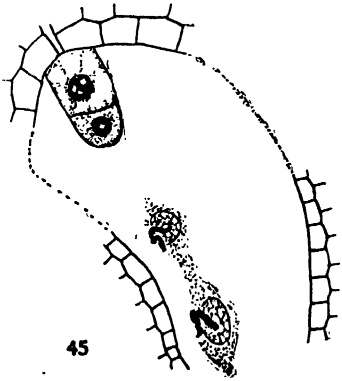

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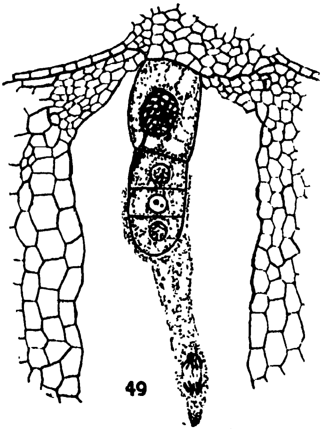

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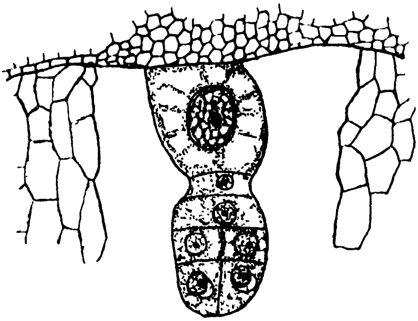

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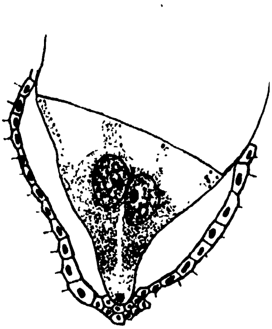

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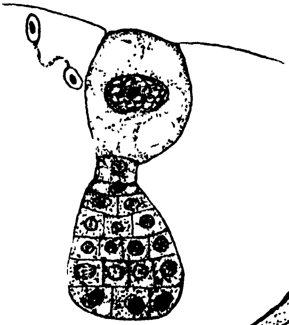

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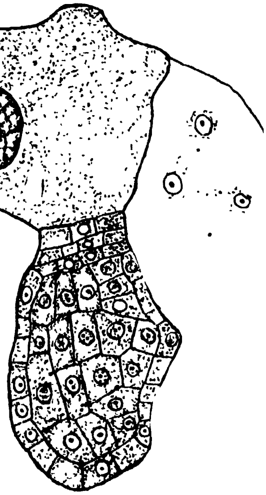

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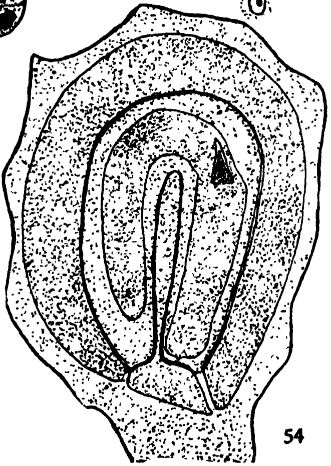

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A NOTE ON FIRST INTEGRALS.

By C. N. Srinivasiengar, D.Sc.

(*Department of Mathematics, Central College, Bangalore.*)

For an ordinary differential equation of the second order $F(x,y,y',y'')=0$, the following facts are well known:—*viz.*, (1) If we know two independent first integrals, the complete primitive is obtained by eliminating y' between them. (2) If we know one first integral, the primitive can be obtained by solving this differential equation of the first order. I desire to draw attention to a paper in *Crelle's Journal*, Bd. 118, pp. 158-162 by Alf Guldberg, in the course of which is mentioned the following peculiar mode of obtaining the complete primitive from a (properly chosen) first integral. For the equation $xyy''+xy'^2-yy'=0$,

$$V(x, y, y', a) \equiv y' - \frac{x(y^2+a^2)}{y(x^2+a)} = 0$$

provides a first integral. The elimination of y' between $V(x,y,y',a)=0$ and $V(x,y,y',b)=0$ gives the complete primitive $y^2=(a+b)\,x^2+ab$, which can be written $y^2=c_1\,x^2+c_2$. It thus appears that *the primitive is obtained from a single first integral without any quadrature.*

It can be easily verified by examples that this method is not in general successful. If we take any first integral $V(x,y,y',a)=0$ of any differential equation $F(x,y,y',y'')=0$, the elimination of y' between $V(x, y, y', a)=0$ and $V(x,y,y',b)=0$ leads in general either to the relation $a=b$ or to an equation which does not satisfy $F=0$. What then are the peculiar characteristics of the first integral given by Guldberg? Can such a first integral be always found?

The essential fact is that in Guldberg's example, *the two roots for* a *of the equation* V (x, y, y', a) = 0 *correspond to two independent first integrals.** In other words, $V(x,y,y',a)=0$ may be taken as the rationalised form of one first integral, and $V(x, y, y', b)=0$ as the rationalised form of a second first integral.

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* **I am obliged to Dr. R. Vaidyanathaswamy for this idea.**

This does not hold good in the general case $a^2L-2aM+N=0$, where L, M, N are functions (not necessarily algebraic rational) of x, y, y'. Let the two roots of a be $a=\lambda(x, y, y')$; $a=\mu(x, y, y')$. Then the values of y'' given by the equations $\frac{\delta\lambda}{\delta x}+y'\frac{\delta\lambda}{\delta y}+y''\frac{\delta\lambda}{\delta y'}=0$ and $\frac{\delta\mu}{\delta x}+y'\frac{\delta\mu}{\delta y}+y''\frac{\delta\mu}{\delta y'}=0$ must satisfy the differential equation of the second order derived from $a^2L-2aM+N=0$. These values will in general be different. The two values of a correspond to the first integrals of two different equations given as branches of y'' of $F(x, y, y', y'')=0$. In case F happens to give only one branch for y'', the equation $a^2L-2aM+N=0$ furnishes a "Guldberg first integral" provided that λ and μ are functionally independent.

Let $u(x, y, y')=c_1$; $v(x, y, y')=c_2$ be a pair of independent first integrals of any equation $F(x, y, y', y'')=0$. u and v are not necessarily algebraic or rational. The necessary and sufficient conditions that

$$V(x, y, y', a)\equiv a^2L(x, y, y')-2aM(x, y, y')+N(x, y, y')=0$$

may be a Guldberg first integral may be stated as follows:—

(i) V is a function of u and v, but not a function of u alone or of v alone.

(ii) V or VW should not be expressible as a function of any function of u and v, which is free from the constant a (where W is a function of x, y, y' free from a); for instance, if $V\equiv a^2-2auv+2$, V is a function of uv. In such a case, λ and μ are not independent and the two roots of a give only one independent first integral.

The condition that V should not be a perfect square is included in (ii). It is assumed that L, M, N do not admit of a common factor.

When V satisfies these conditions, the two roots for a, *viz.*, $\lambda(x, y, y')$ and $\mu(x, y, y')$ are given as functions of u and v. $\lambda(x, y, y')=$ constant and $\mu(x, y, y')=$ constant may therefore be regarded as a pair of independent first integrals of the given equation. The elimination of y' between $\lambda(x, y, y')=a$ and $\mu(x, y, y')=b$ is equivalent to the elimination of y' between $V(x, y, y', a)=0$ and $V(x, y, y', b)=0$.

This explains the theory underlying the Guldberg first integral.

It is now clear that for any equation $F(x, y, y', y'') = 0$ we can construct a Guldberg first integral in an infinite number of ways by the help of a pair of independent first integrals $u = c_1$, $v = c_2$. Thus $a^2 - au + v = 0$, $a^2 - a(u+v) + 2(u^2 + v^2) = 3$, $a^2 - au^2 + v^3 = uv$, etc.

It is possible to obtain Guldberg integrals starting from the complete primitive $f(x, y, c_1, c_2) = 0$ by transforming the parameters c_1 and c_2 into suitable *symmetric functions* of two parameters a and b. Thus Guldberg uses for his example $y^2 = c_1 x^2 + c_2$, the substitutions $c_1 = a + b$, $c_2 = ab$. The first integral derived after such a substitution is, however, not always necessarily a quadratic function of the parameter.

Generalisations for differential equations of higher orders are easily made. Thus for an equation of the third order, a Guldberg first integral must be of the form $\phi(c, u_1, u_2, u_3) = 0$ where ϕ involves c in the third (or higher) degree, and $u_r(x, y, y', y'') =$ constant, $(r = 1, 2, 3)$ are three independent first integrals.

From the practical point of view, for solving a given differential equation, the Guldberg integral is of little use, since it is very unlikely that by any process we can arrive at a Guldberg integral without the help of the ordinary first integrals or of the complete primitive. But the existence and the property of this peculiar type of first integral deserve notice.

Example:—For the equation $y''(1+xy) + 2y'(y - xy') = 0$, verify that $c^2(y - xy') - c(y^2 + y') + (1 + x^2 y') = 0$ provides a first integral, and that the complete primitive can be obtained without further integration.

THE DIGESTIVE TRACT OF *EMYDA VITTATA* (KELAART).*

BY A. NARAYANA RAO, B.Sc.
(Department of Zoology, Central College, Bangalore.)

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INTRODUCTION.

The reptilian alimentary canal has been the subject of study by a number of investigators and attempts have been made to correlate the general morphology with the functional activity of the different regions of the digestive tract. Though the histology of the reptilian alimentary canal has been studied at length, an attempt to correlate the histological details with the diet of the animal has not, so far as is known to me, been made. The present paper sets forth the results of my investigations on the Digestive Tract of *Emyda vittata* (Kelaart) undertaken with a view to offer a satisfactory explanation for the persistence of certain primitive features in the gut of this animal. An attempt is also made to correlate these features with the diet of the reptile.

This work was undertaken at the suggestion of Professor C. R. Narayana Rao and I must acknowledge my debt of gratitude for his very valuable suggestions and guidance in the course of this work. I must also hasten to express my thanks to Dr. A. Subba Rao of the University Medical College, Mysore,

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* Thesis approved in partial fulfilment of the requirements for the M.Sc. degree examination of the University of Mysore.

for his very generous help both as regards material and literature. I have also received considerable help from the authorities of the Indian Museum, Calcutta, and Professor R. Gopala Iyer and Dr. S. G. M. Ramanujam of the Madras Presidency College, to all of whom I wish to express my gratitude.

A preliminary note on the subject was communicated to the Indian Science Congress at its Bangalore Session in 1931.

LITERATURE AND PREVIOUS WORK.

In reviewing the literature on the morphology and physiology of the reptilian alimentary tract, one finds a want of unanimity of opinion regarding both the structure and function of the different regions of the alimentary canal. Workers from very early days have investigated the subject but did not possess the advantages, available to their successors, of modern technique and methods of investigation. In their approach to the subject they emphasised the evolutionary or the phylogenetic aspect more than that bearing on comparative histology or physiology.

The correspondence between the diet of the animal and the development of the different parts of the intestine is a well-known fact. The development of the cæcum in the horses is correlated with the animal's diet chiefly consisting of matter rich in cellulose. The food passes in this animal rapidly through the stomach and the intestine and retained in the cæcum where digestion and absorption take place. Tullberg[18] in his papers on the Rodents has expressed that digestion and absorption of cellulose take place in the cæcum and the colon. The digestion of this kind of food is dependent not only on the length and width of the intestinal tract but on the slowness with which the food passes through these parts of the intestine. In fact animals develop structural adaptations for the purpose of retaining or retarding the passage of food.

Among the earliest investigators on the reptilian digestive tract Einar Lonneberg[7] studied the gross morphological structure of the intestine of the different groups of reptiles. He has considered the general shape, arrangement and length of the intestinal canal and especially the development of the cæcum in the lizards belonging to the different families. The development of the cæcum depends entirely on the manner of the entry of the small intestine into the large intestine and a cæcum in varying degrees of development is present in some and entirely absent from others. Tullberg[18] believes that a reduction of the cæcum is the result of a diet consisting of such substances as amylum, fat and protein, the digestion of which may take place in the small intestine without the help of the cæcum. Vegetable food may, just as well as a carnivorous diet, lead to the loss of the cæcum. The origin of the cæcum is to be found in the distinction between the small and the large intestine, a feature which manifests itself by the development of the sphincter and the valve.

The differentiation of the stomach into different regions based on structure and function, also depends on the nature of the diet. The reptiles present different degrees of development of the pyloric tract—a region intercalated between the pyloric orifice and the more muscular portion of the stomach.

The length and width of the intestinal region are greatly influenced by the diet of the animals. The effect of the vegetative diet on the intestinal canal is most conspicuous within the group of herbivorous iguanas, in which the small intestine is twice or thrice as long as it is in the insectivorous iguanas. The longitudinal plications of the intestine in the lizards, according to Lonneberg,[7] allow a considerable increase in the dilatory powers and this is more pronounced in animals lacking the powers of mastication and the breaking powers of the stomach. The diet of the animals has considerable influence on the development of the different parts of the intestine and the researches of Lonneberg[7] show that reptiles develop remarkable adaptations to their diet.

Concerning the histology and physiology of the reptilian alimentary tract, there is, as in the case of morphology, considerable divergence of opinion both as regards the structure of the glands and the functions of the component cells. Partsch[12] describes in lizards and snakes cylindrical cells lining the stomach while finely granular cells line the tubular glands. The transitional regions between the neck and body of the gastric glands are lined by mucous cells. Langley[6] described oxyntic cells in the fundic glands of *Coluber natrix.* The neck and foveolæ of these glands, the pyloric glands and the superficial layer of the stomach are lined by mucous cells. Oppel[8,9] described in the alligator mucous cells from the gastric epithelium and foveolæ. The neck region of the glands is lined by flat cells while the fundic part is lined by polyhedral cells. He further described in the crocodiles two types of gastric glands,—(1) the gastric juice glands composed of polyhedral cells with granular protoplasm making up the major portion of the glands, and (2) mucous glands whose walls are made up of mucous cells which continue right up to the surface of the glands. Beguin[2] found three types of cells in the fundic glands of lizards and snakes—(1) surface cells related to the mucous cells; (2) neck cells with no sharp line of demarcation between them and the surface mucous cells; and (3) granular cells making up the body of the glands. Reese[14] has described in the stomach of the alligator only one kind of cell in the cardiac, fundic and pyloric regions of the stomach. Staley[16] working on the gastric glands of the alligator comes to the conclusion, based on histological and experimental evidence, that the cells lining the free surface of the stomach are not strictly comparable to the true mucous cells. The neck and bodies of the gastric glands are composed of parietal cells.

The preceding survey presents in brief the main points of view on the relation between the diet of the animal and the morphology of the alimentary tract and the structure of the gastric glands with the functions ascribed to the component cells.

MATERIAL AND METHODS.

The locally available mud turtle *Emyda vittata* (Kelaart) was kept alive and under observation in the laboratory tank. The digestive tract was dissected in normal saline solution and fixed in various fixatives including Bouin's picro-formol-acetic, Zenker's fluid, aqueous corrosive sublimate, Bensley's fluid and 10 per cent. formalin. The sections were stained in hæmalum, Heidenhain's hæmatoxylin followed by eosin. Material fixed in sublimate solution was stained with Bensley's neutral gentian as a specific for zymogen granules in the chief cells of the gastric glands. I have also tried, at the very kind suggestion of Dr. A. Subba Rao, Bensley's special technique for the demonstration of oxyntic cells in the gastric glands. Mayer's mucicarmine has been used as a specific stain for the mucous cells. Mallory's triple and Pacini's have also been employed.

GENERAL MORPHOLOGICAL NOTES.

Emyda vittata is commonly found living near the water margins of the local tanks, burrowing in soft earth. It enters the water during the hot season when the earth is caked and so thoroughly at home is this animal in its watery habitat that it may be kept in the laboratory tanks without any means of resting either above or near the surface. It flourishes under these conditions for any length of time.

I have observed in the laboratory tanks that these animals remain under water for prolonged periods and occasionally they stretch out their elongated necks to reach the surface and even then only the snout is thrust out of water to take in air. While completely submerged and lying on the bottom of the tanks, the animals are seen to swallow copious quantities of water. Gadow (*Cambridge Natural History*, *Amphibia & Reptiles*, Vol. VIII) has observed that when an Emys or Clemmys is suddenly taken out of water, it squirts out a stream of this fluid through the vent and *Emyda vittata* behaves similarly when it is taken out of the laboratory tanks.

The animal leaves the watery habitat frequently wandering into the cattle-sheds of the neighbouring villages in quest of food. It then feeds on tender vegetation, insect larvæ and animal dung. The contents of the stomach of a freshly captured specimen show remains of decaying animal and vegetable matter, small fish and crustacea. The specimens kept in the laboratory tanks refuse to take anything and stand surprisingly prolonged periods of starvation. The inference is that the animal should have a decided liking to decaying vegetable and animal matter in its free state.

The digestive tract, fairly uniform in appearance, is in the form of a tube which *in situ* is thrown into a number of transverse loops (Fig. 1). In a specimen whose carapace measured about 25 cms. the intestinal region was arranged in seven transverse loops. The transverse folds are firmly supported by a thick mesentery. The outer wall of the intestine and the mesenterial folds together with the spaces between the folds are loaded with fat, white and sometimes yellow, having a peculiar and disagreeable odour. Omitting the anterior and posterior divisions of the alimentary canal, the intestine alone will measure nearly four times the length of the carapace. Judged therefore from the length of the intestines and the number of convolutions into which they are thrown, *Emyda vittata* shares along with the other Amniota the more advanced character of an alimentary canal far longer than the cavity in which it is placed. Associated with this advanced character is a definitely well-marked primitive feature, *viz.*, the occurrence of a longitudinal ridge-like typhlosole, extending throughout the length of the midgut. The structure of the intestine therefore presents an anomaly possessing advanced and manifestly primitive features.

Externally the digestive tract is only partially differentiated into definite morphological regions. We can recognise the following morphological regions in addition to the buccal cavity : pharynx ; œsophagus ; stomach ; duodenum ; intestine ; rectum and cloaca. The pharyngeal region is situated in slightly behind the buccal cavity and its posterior continuation is the œsophagus. Corresponding to the long neck, the œsophagus is a fairly long tube. The histology of the different regions gives sufficient justification for segregating not merely the pharynx from the œsophagus but also points to the division of the latter into an anterior and posterior region. There is no external indication of the passage of the œsophagus into the stomach except that at the cardiac end the former shows a slight dilatation. The transition is very clearly seen when one opens the œsophagus and descends into the stomach and it may roughly be taken that the transition takes place slightly posterior to the region of the axilla.

The stomach is very simple and tubular. It extends in an almost straight line parallel to the longitudinal axis of the animal. It lies to the left of the median axis. As stated above there is no external indication of the transition of the œsophagus into the stomach but internally just opposite to the region of the axilla, the complicated œsophageal folds give place to the simple longitudinal folds of the gastric mucosa. Even as regards the number of the folds there is considerable diminution. 7 or 8, more or less equal, mucosal folds are seen in the stomach. There is no pyloric valve but towards the pyloric end, the gastric mucosal folds are curved backwards (Fig. 2).

The stomach has two orifices—the œsophageal or the cardiac and the pyloric. There are two curvatures—the greater and the lesser. The portion of the œsophagus entering the body cavity is curved slightly to the left and becomes continuous with the cardiac end of the stomach. The right margin of the œsophagus is continuous with the lesser curvature. The pyloric orifice lies to the left of the middle line.

The intestine is very long and uniformly tubular and could be conveniently divided into the rectal and pre-rectal regions, the latter including the duodenum and the intestine. The distinction between the duodenum and the intestine is purely arbitrary and together they make up three-fourths of the entire length of the intestinal region. The cæcum is absent. The sphincter and the valve described by Beguin[2] and Lonneberg[7] in some reptiles are absent.

The pre-rectal region is characterised by the presence of intensely plicated mucosal folds and running the entire length of the pre-rectal region is a dorsal longitudinal ridge which commences almost near the duodenum, 6-7 cms. from the pyloric orifice of the stomach. The presence of this longitudinal ridge reduces the cavity of the pre-rectal region of the intestine into a semilunar slit. I shall refer later to the histology of this interesting structure. The rectal region is characterised by the absence of the marked plications of the mucosa. The rectum opens into the cloaca which also receives the genital ducts and the allantoic bladder.

HISTOLOGY OF THE DIGESTIVE TRACT.

The following layers are present in the digestive tract :—

Serous Layer.—A thin layer of areolar tissue with some superimposed connective tissue cells.

Muscle Layers.—Outer longitudinal muscle layer consists of a thin sheet of muscles having longitudinally disposed fibres and an inner circular layer of transverse fibres.

Sub-Mucosa.—This consists of loose areolar tissue in which are embedded numerous small blood vessels, lymphatics and nerve plexuses.

Mucous Layer.—This forms the lining of the cavities and is of variable thickness according to the region to which it belongs.

These layers vary in certain marked features all along the tract. The muscle layers and the mucous membrane show the greatest histological variation while the other two layers are fairly uniform, though the degree of development of the sub-mucosa differs in some regions. The muscularis mucosæ which separates the mucosa from the underlying sub-mucosa is usually well developed in the region of the stomach, less so in other regions. An interesting feature of this layer is that it is made up of exclusively circular fibres.

Buccal Cavity.—The buccal cavity extends from the lips to the pharynx and the epithelium is lifted up in a series of low longitudinal folds, the folds being more numerous and pronounced at the sides of the cavity. The buccal mucosa consists of (*a*) a stratified epithelial layer and (*b*) a layer of connective tissue underlying the mucosa. The basement membrane is not present.

The epithelium which lines the buccal cavity is stratified and the stratification is suggested by the innumerable nuclei (Fig. 3). The epithelium is 10-14 cells in thickness. As a consequence of the absence of definite cell outlines, it is not possible to distinguish between the flattened polyhedral and cylindrical calls that make up the epithelium. The nuclei of this layer are very small, spherical towards the surface and ovoidal towards the basal region. Each nucleus possesses a distinct nucleolus and a number of chromatin granulations. Mucous cells are not present in large numbers. The distribution of these cells is of a very restricted nature and extensive regions of the buccal mucosa are without them. When present they alternate irregularly with the superficial epithelial cells. Each mucous cell is filled with a considerable quantity of mucus and opens into the buccal cavity by a wide aperture. The cells are usually of the same diameter throughout and do not narrow into a neck in the distal part. The nucleus of the mucous cell is flattened and basal in position. The stratified epithelium is implanted on the underlying sub-mucosa.

The sub-mucous layer is remarkable for the numerous blood-vessels and lymphatics contained in it. Besides it is traversed by a system of lacunar spaces. Connective tissue fibres are present in the deeper parts of the mucosa by which the buccal membrane is attached to the bones of the skull. Buccal glands are absent.

Pharyngeal Region.—The pharynx is the division of the alimentary canal intervening between the buccal cavity and œsophagus. Certain histological differences justify the treatment of this part of the alimentary tract immediately succeeding the buccal cavity as a definite pharynx. The epithelium like that of the buccal cavity is stratified but consists of a fewer cell layers. The pharyngeal mucosa is intensely folded reducing the lumen into a series of radiating canals. Definite finger-like processes of areolar tissue extend into these mucosal folds.

Two kinds of cells constitute the epithelium—cylindrical epithelial cells and mucous cells, the latter being restricted in their occurrence. In certain regions of the pharynx the superficial cells are cylindrical while the deeper ones are polygonal. The epithelium is distinctly stratified and shows certain regional variations. In the anterior region the mucous cells are not numerous while as we pass towards the œsophageal end there is a gradual increase in the number of these cells.

The pharynx is a highly muscular organ. The musculature consists largely of circularly disposed bands of striated muscle fibres which become continuous with those of the œsophagus and a number of loosely arranged longitudinal bundles. We can make out an internal and an external layer of such longitudinal bundles with the circular layer between them (Fig. 4). Towards the posterior region of the pharynx the musculature is gradually reduced till finally in the œsophageal region we have a comparatively narrow band of circular and a narrower band of longitudinal muscles.

The scarcity of the mucous cells, the intense folding of the mucosa reducing the cavity into a number of radiating canals, the enormous development of the thickness of the wall and the presence of an internal and external bundle of loose longitudinal muscles are the important characters which distinguish the pharynx from the œsophagus.

The exaggerated development of the muscle layers encroaches upon the sub-mucosa. The sub-mucous layer differs little from the corresponding region of the buccal cavity. The tissue, however, is spongy and loosely compacted.

Oesophagus.—The reptilian œsophagus has been the subject of investigation by numerous authors and the results obtained are of a contradictory nature. Beguin[2] describes in his study of the œsophageal mucosa of reptiles, a transition from the primitive condition of the lower vertebrates to the more complex characters of the higher vertebrates. In the Saurians the œsophageal epithelium is simple and cylindrical with a predominance of ciliated cells. In *Anguis fragilis* the ciliated cells gradually diminish in numbers. In the Ophidians the simple cylindrical epithelium shows a predominance of mucous cells. Among the Chelonians, in *Emys europea*, the œsophageal epithelium is pavemented and stratified with a predominance of mucous cells. Hoffmann[5] has described in *Testudo græca* a stratified epithelium and in the same form Maria Sacchi[15] describes a ciliated epithelium. Gianelli and Giacomini[4] described in the same animal a pavemented stratified epithelium. Finally Oppel[8,9] has found the cells so indistinctly demarcated from each other that he found it impossible to decide whether the epithelium is stratified or not.

Developmentally the part of the digestive tract between the pharynx and the entrance of the bile duct develops into the œsophagus, stomach and that part of the intestine known as the duodenum. The stomach and the duodenum are separated by the pyloric valve when such a structure is present but it is difficult to draw a clear line of demarcation between the œsophagus and the stomach.

The œsophagus in *Emyda vittata* is very much elongated corresponding to the length of the neck and structurally is well adapted for conducting the food to the seat of digestion and absorption. The transition of the pharynx into the œsophagus is very obvious if we examine the nature of the œsophageal mucosa. The enormous number of mucosal folds characteristic of the pharynx give place to the comparatively simple folds of the œsophagus. In transverse sections of the posterior portions of the œsophagus I could recognise 8-10 major folds (Fig. 5). Based on the nature of the mucosal folds and the kinds of cells composing the epithelium, we could distinguish two regions of the gullet—an anterior and posterior. In the anterior œsophageal region the mucosal folds like those of the pharynx are narrow finger-shaped processes containing extensions of the underlying sub-mucosa while posteriorly we find the folds becoming more and more flattened. Again in the anterior region, the epithelium is stratified with a minimum of mucous cells while in the posterior regions the mucous cells predominate.

The epithelium is composed of two types of cells—cylindrical epithelium and mucous cells. In the anterior portion of the œsophagus the surface is lined by cylindrical cells with a few goblet cells interspersed here and there. In the posterior regions, the entire free surface of the œsophageal mucosa is occupied by mucous cells which alternate regularly with the cylindrical cells. Mucous cells are numerous in the depressions of the mucosa where they are found in several layers (Fig. 6). The basal portions of the epithelium are occupied by a bed of two or three layers of closely packed nuclei which probably belong to the other cells of the epithelium. The nuclei are ovoidal and in the deeper regions are small and spherical.

Both the nuclei contain numerous chromatin granulations, one of which slightly bigger than the others represents the nucleolus.

Sub-Mucous Coat.—The sub-mucosa of the œsophagus differs from that of the pharynx. It is very spongy and contains numerous blood capillaries, lymphatics and a system of lacunar spaces. Besides at points where the mucosa is deeply folded, we find that the basal regions are occupied by large lymphatic nodules. These lymph nodules appear as rounded or oval masses and stain very conspicuously by reason of the nuclei of its numerous leucocytes.

Muscular Coats.—The muscular coat consists of an outer longitudinal and an inner circular layer and the bundles of both are very compact. What distinguishes the œsophagus from the pharynx besides the differences in the nature of the cells constituting the epithelium, is the development of a compact sheet of connective tissue in which are embedded both the outer longitudinal and inner circular bundles (Fig. 7). Sections of the œsophagus stained either with Mallory's triple connective tissue stain or Pacini's show that this sheet is in the nature of connective tissue. It takes a deep blue stain. The fibres of this connective tissue sheet run in a direction perpendicular to that of the sub-mucosa and the former is clearly demarcated from the latter. We find blood-vessels and lacunar spaces even in this connective tissue sheet as in the submucosa. The fibres of this sheet could be easily traced through the layer of circular muscles to the outer longitudinal layer. There could be no doubt that this connective tissue sheet confers on the œsophageal wall considerable degree of firmness and consistency.

The longitudinally disposed layer is comparatively little developed and is surrounded by connective tissue. The layer is in the form of little bundles and is covered over externally by the serous coat. The circular layer consists of elongated fibres, spindle shaped and possesses an ovoidal nucleus. The longitudinal and circular bundles are separated by a layer of connective tissue which is continuous with the connective tissue sheet above referred to.

The horny papillæ of the œsophagus and the œsophageal glands referred to by other authors are absent in this reptile.

Stomach.—The gastric mucosa is nearly of uniform thickness varying from 0.75 to 0.8 mm. The epithelium consists of simple cylindrical cells and each contains an ovoid nucleus placed towards the middle of the cell with a nucleolus and a number of chromatin granulations.

Just opposite to the region of the axilla the complicated œsophageal folds give place to the mucosal folds of the stomach. The transition is first of all marked by the diminution in the number of folds towards the cardiac end. I can make out seven to eight large more or less equal long longitudinal mucosal folds. Another characteristic sign of transition is the marked disappearance of mucous cells. A longitudinal section passing through the posterior end of the œsophagus and the cardiac end of the stomach shows this abrupt change. The stratified œsophageal epithelium is continued into the superficial epithelium of the stomach. The manner of transition is illustrated in Fig. 8. Close to the limit between the two regions, the stratified epithelium is of considerable thickness and if the lower line of the epithelium is followed, it will be seen that as it approaches the junction, the lowermost cells of the œsophageal mucosa becomes directly continuous with the simple columnar epithelium of the stomach while the layers above it cease abruptly.

I recognise throughout the different regions of the stomach two main types of glands. The first type composed of long tubular glands, the walls of which are lined by cubical cells with granular protoplasm. The cylindrical surface epithelial cells become continuous with the lining cells of the foveolæ and the neck of the glands (Fig. 9). The second type—the mucous glands—consist of mucous cells which exclusively make up the gland. These cells in some cases extend upto the surface of the stomach. The deeper portions of these glands are broader than the corresponding regions of the first type of glands (Figs. 13 & 14).

Regarding the distribution of the two types of glands, I find that the mucous glands are numerous towards the deeper parts of the mucosa. In the anterior or the cardiac region of the stomach the mucous glands are very rare (Fig. 9) and gradually increase in number as we go towards the pyloric end where they are very abundant (Figs. 11 & 12). The glands which are very broad towards the base reach the surface of the gastric epithelium and are throughout lined by mucous cells.

The gastric glands are tubular (Fig. 10) extremely deep and throughout the mucosa are very much pressed against each other and only a feeble quantity of connective tissue separates individual and groups of gastric glands. A number of glands open into each foveolæ and the lumen of each gland is very narrow.

I can recognise in the glands of the stomach two types of cells (*a*) one characterised by their cubical appearance with a centrally placed large nucleus with a distinct nucleolus and many chromatin granulations and (*b*) the hyaline type of large cells with an extremely compressed basally placed nucleus. In the constitution of the gastric glands of the second type, only mucous cells are present and the mucous cells do not alternate with the granular cells as described by Beguin[2] nor do we find groups of such cells alternating with groups of the first type of cell. The entire basal portions of the gland are made up by the mucous cells. The nucleus of the hyaline type of cell is usually surrounded by a very slight protoplasmic mass.

As by an examination of the glands I cannot distinguish the cardiac, fundic or the pyloric regions, either by the degree of development of the glands or by the presence of special cells like the oxyntic cells, I propose to distinguish the stomach into the anterior, middle and posterior regions, the first and the last corresponding to the cardiac and pyloric ends.

The Surface Epithelial Cells and the Cells lining the Gastric Glands.—Langley,[6] Hoffmann,[5] Oppel[8,9] and others regard the surface epithelial cells as true mucous cells but Osawa[10] regards them as modified epithelial mucous cells. I have tried several of the mucous stains including Mayer's mucicarmine, Toluidin blue and other specific stains. The surface cells and those lining the upper portions of the foveolæ when stained with the mucous stains show a faint blue colour in the end of the cell towards the lumen of the gland. The cytoplasm is homogeneous. In contrast to this almost negative reaction the hyaline cells towards the deeper portions of the second type of glands take an intense blue stain. This suggests that only a part of the surface cells are mucous in nature while the staining reaction gradually diminishes towards the bottom of the foveolæ. The behaviour of the surface cells throughout the stomach is the same.

The results show that true mucous cells cannot be demonstrated in the surface epithelium of the stomach.

The gastric glands as stated above consist exclusively of either chief or pepsin-forming cells or mucous cells. The results of my observations go to show that the oxyntic cells or parietal cells are absent. Towards the cardiac and a greater part of the stomach the glands of the first type are composed of cylindrical cells related to the surface epithelial cells, peptic or chief cells making up the neck and body of the gland. Mucous cells form the component cells of the second type of gland.

Gastric Sub-Mucosa.—The gastric sub-mucosa is separated from the gastric mucosa by the development of muscularis mucosæ. The degree of development of this layer differs in different regions. It consists of a number of circular muscles consisting of elongated fibres with spindle-shaped nuclei. The longitudinal fibres do not form part of the muscularis mucosæ. In fact in certain regions of the stomach the muscularis mucosæ is so well developed that the appearance is suggestive of the fact that the inner circular layer of muscles belonging to the thickness of the wall is divided into an inner and outer, the former separated from the latter by a well-developed sub-mucous layer and occupying the position of muscularis mucosæ.

The sub-mucous coat of connective tissue lies beneath the muscularis mucosæ. It extends into the gross epithelial folds of the mucosa and therefore its thickness is variable. The extension into the gastric folds is a marked feature and the loose character of the tissue bespeaks of adaptation to the various changes of the gastric epithelial folds during digestion. The fibres pursue a direction parallel to the muscular and epithelial surfaces with which they are in contact.

The Gastric Muscles.—The gastric muscular coat consists of an outer longitudinal and an inner circular layer. The circular layer is by far the thicker of the two. In certain regions of the stomach the longitudinal fibres show a tendency for an exaggerated development when the bundles appear as a number of fasciculi surrounded by connective tissue fibres. Both striated and non-striated fibres are present.

Intestinal Region. -The transition of the stomach into the intestine is marked externally by a constriction of the stomach towards the pyloric end and internally the simple longitudinal folds of the gastric mucosæ are replaced by a highly plicated intestinal mucosa. I have not observed the existence of the pyloric valve. I find the usual four coats of the intestine and the sub-mucous layer is variously developed.

The absence of the cæcum and the uniform tubular nature of the intestine present difficulties for distinguishing the small and the large intestine. Histological examination of this part of the digestive tract justifies the division of the intestine into a pre-rectal and a rectal region. Terminally the rectum opens into the common cloacal region

The transition of the gastric into the intestinal mucosa is marked by the absence of the gastric glands. The cylindrical epithelial cells lining the surface of the stomach pass imperceptibly into the cylindrical cells forming the surface epithelium of the intestine. The transition is further marked by the appearance of a number of wandering cells between the surface epithelial cells of the intestine. The nuclei of these wandering cells stain very deeply. Besides, the goblet cells absent in the gast ic mucosa appear in the intestine, though not in such large numbers in which they occur in the pharynx and œsophagus.

The epithelium is composed of cylindrical cells. The nucleus is ovoidal with a number of chromatin granulations and is situated roughly at about the middle of the cell. The occurrence of nuclei at slightly different levels in the row of cells suggests a multinucleate condition. Wandering cells are abundant between the epithelial cells. A distinctly striated top plate covers the surface of the epithelium. Towards the base of the cellular layer, we find an aggregation of nuclei and some of the nuclei of this region show conspicuous heavily stained chromatin masses. These appear to be actively dividing cells and represent the layer of regenerating cells.

The plications of the mucous membrane in the pre-rectal region give rise to finger-like processes—the villi. The villi are very characteristic of the intestine, very large and numerous (Fig. 13). They are generally long, slender and towards the base are flattened out. Occasionally two or three villi are connected together at various points, enclosing a space between them. The enclosed spaces are consequently lined by cylindrical epithelial cells. Each villus consists of a prolongation of the mucous membrane proper and is covered externally by the columnar epithelium. It encloses within blood vessels, one or more lymphatics and some plain longitudinal muscular fibres. In the centre of each villus lie one or more lacteals lined by flattened endothelial cells. Besides the lacteals and blood vessels, the villus has a number of connective tissue corpuscles. Neither the muscularis mucosæ nor the sub-mucosa extends into the villus.

The shape of the villi is not uniform. In some regions they are large and foliaceous while at others they are long and slender. The size of the villus is also subject to wide variation. The goblet cells are very rare but are certainly not absent in the region of the intestine.

The pre-rectal region of the intestine is characterised by the presence of the two kinds of secreting glands—crypts of Lieberkuhn and the intestinal glands while the rectal region shows only the intestinal glands. A point of interest is occurrence of glands throughout the intestinal region. The crypts are formed by the invagination of the mucous membrane into the thickness of the layer. The surface epithelium is carried into the crypts. Between these crypts the reticular tissue of the mucous membrane with lacteals and blood vessels is present. The epithelium of the glands or the crypts is of the same nature as that covering the general surface of the intestine. Usually towards the fundus or the deeper portions, the invagination slightly broadens and towards this region there is an enormous increase in the number of leucocytes. The intestinal crypts show a tendency to branch and form compound crypts.

The mucous membrane both in the rectal and pre-rectal regions is separated from the sub-mucosa by the muscularis mucosæs. This layer presents varied degree of development and consists of chiefly circular muscle fibres, each fibre being elongated and provided with a compressed spindle-shaped nucleus.

Sub-Mucous Layer.—So far as the structure of the sub-mucosa is concerned, there is not much difference between the layer in the pharynx and œsophagus and the one present in the intestine. The difference is only in the degree of development. In the pre-rectal region the sub-mucous layer is greatly reduced consisting of a few connective tissue fibres with a number of blood vessels. But in the region of the longitudinal ridge, the sub-mucous layer is enormously developed and shows the characteristic white and elastic fibres with a number of blood vessels, lymphatic nodules and spaces.

Typhlosole.—This is a very characteristic structure observed for the first time in the intestine of a vertebrate fairly high in the scale of evolution. It is a longitudinal ridge along the mid-dorsal line and depending into the cavity of the intestine. The mucous membrane with its characteristic villus-like processes extends over the surface of the typhlosole. The development of this structure reduces the cavity of the pre-rectal region of the intestine into a semilunar slit (Fig. 14). The nature of the epithelium is the same as in the other regions of the intestine. The muscularis mucosæ is greatly developed and separates the mucous membrane from the underlying well-developed sub-mucosa. The bulk of the typhlosolar ridge is made up of the most diffused kind of connective tissue. The tissue is fleecy-looking and forms a kind of framework supporting and connecting the mucosa with the outer muscular coats. The sub-mucosa consists of bundles of fine fibrils which do not branch but join one another within the bundles. These fibres are pearly white in appearance when in a bundle and the toughness of the typhlosole is due to these fibres which are known as the collagenous fibres. In addition to these fibres, we find others which run singly branching at intervals and uniting with adjacent fibres. These fibres run nearly straight and are the elastic fibres. In addition to these different types of fibres, we find a number of connective tissue corpuscles and lymphatic nodules (Fig. 15).

Rectum and Cloaca.—The general histology of the rectum is very similar to that of the pre-rectal region. The intense folding of the mucous membrane producing the villus-like processes in the pre-rectal region is replaced by a mucosa which is less folded. The epithelium shows a similar nature and the glands which occur in great abundance in the pre-rectal region are considerably reduced but are nevertheless present (Fig. 16).

The sub-mucous layer is greatly developed and makes up almost two-thirds of the thickness of the wall and shows the inclusions characteristic of this layer in the other regions of the digestive tract. The muscularis mucosæ which shows a great development in the pre-rectal region is absent in the rectum and the sub-mucous layer next the mucous membrane is more compact than the part touching the muscular coats. The spongy nature of the sub-mucous layer next the muscular coats is due to the presence of a system of lacunar spaces.

The musculature of the rectum is much thicker than that of the preceding part of the alimentary canal. The longitudinal layer which is ill-developed and even absent in certain regions of the pre-rectal region of the intestine is very well developed in the rectal region and is almost twice or thrice as thick as the corresponding layer in the preceding part of the intestine. The muscles are arranged in a number of fasciculi. The circular set is thicker than the longitudinal one and consists as usual of elongated muscle fibres with spindle-shaped nuclei.

An interesting feature of the rectal region is the presence of discrete spaces lined definitely by cells, between the longitudinal and circular layers of muscles. Even in the anterior regions of the intestines we find spaces in similar situations. In close proximity of these spaces—some of which are very wide in the mid-gut—I find a large number of blood vessels (Fig. 16).

The mucous layer is plicated and the cells are elongated. The distal portion of the cell is generally very clear, the basal portion being occupied by granular protoplasm. The nucleus is ovoidal and is situated towards the middle. At the base of the epithelium rounded nuclei which represent the cells of renovation are present and we can clearly make out mitotic figures which suggest that active multiplication occurs in this region.

The rectum opens into the cloaca which receives the gential ducts and the allantoic bladder. The epithelium is stratified and the musculature and the sub-mucosa are poorly developed.

VASCULAR SUPPLY AND INNERVATION.

Thapar[17] in his paper on the vascular system of *Varanus bengalensis* describes that the main arteries supplying the gut—the mesenteric and the gastric—arise definitely from the left systemic arch and a similar origin has been noted by Owen[11] and others in the chelonia and crocodilia. The origin of the mesenteric from the left systemic, is according to Thapar[17] a condition which characterises the higher reptilia while in *Heloderma, Uromastix* and *Hemidactylus* the visceral arteries arise from the dorsal aorta after the union of the two systemics.

In the lizards, chelonians and crocodiles the cœliaco-mesenteric is single and subsequently divides into the gastric and mesenteric the former supplying the stomach and the latter the rest of the gut. In *Emyda vittata* the blood supply to the gut is from three vessels which arise independently from the left systemic arch before it joins the right to form the dorsal aorta. The first to be given off, the gastric besides supplying the different regions of the stomach sends a branch anteriorly to the œsophagus. Of the other two vessels, the anterior and posterior mesenteric arteries, the anterior arises close to the gastric rudiment and supplies the duodenum and the post-duodenal region. The posterior mesenteric is by far the largest artery arising from the left systemic and as soon as it leaves the systemic gives rise to a number of branches which proceed to supply the several transverse loops of the intestine. This vessel is concerned mainly with the supply of blood to the posterior parts of the intestine, besides sending a prominent branch to the spleen.

The digestive tract gets its supply of nerves from the branches of the Vagus. The nerves form a ganglionated plexus between the layers of the muscular coats and the sub-mucous layer from where fibres pass into the muscularis mucosæ. Some of the fibres penetrate into the stratified epithelium. In the region of the stomach the nerves form plexuses as in the other parts of the alimentary canal between the layers of muscles and in the sub-mucous layer. Fibres pass from the plexuses into the mucous membrane.

DISCUSSION.

The digestive tract of *Emyda vittata* presents certain features of interest both morphologically and histologically. The absence of horny papillæ in the œsophageal region and the pyloric valve has been noticed. The intestine could roughly be divided into a rectal and pre-rectal region with no obvious external morphological indication of the transition of the former into the latter. The development of the longitudinal ridge in the mid-dorsal line of the pre-rectal region of the intestine, the absence of the cæcum and other valvular devices in the digestive tract, the structure of the gastric glands are among the interesting characters of the digestive tract of this reptile.

Turning our attention to the development of the typhlosole, I might state at once that it is a very primitive character in a higher vertebrate. Sir Richard Owen in his *Comparative Anatomy and Physiology of Vertebrates* has a short note on the intestinal tract of the Chelonians. He observes that " in the tortoise *Testudo indica* the inner surface of the small intestine is reticulate ; in *Testudo tabulata* and *Emys europea* it is disposed in small and numerous longitudinal rugæ." Beyond this brief reference and a casual mention of the elongated midgut in the Chelonia by Gegenbaur[3] I could obtain no further information on the structure of the intestine of the Chelonians.

In writing on the development of the intestines among the Vertebrata, Balfour in his *Comparative Embryology* observes that " in certain vertebrates the intestine retains its primitive character as a straight tube ; and in these types its anterior part is characterised by the presence of a peculiar fold which in a highly specialised condition is known as the spiral valve."

This structure appears in its simplest form in *Ammocœtes*. It consists of a fold in the wall of the intestine giving the lumen of this canal a semilunar form and taking a half spiral.

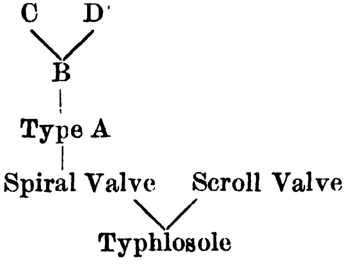
In the Elasmobranchii a fold similar to that of the *Ammocœtes* makes its appearance in the embryo. This fold from the first is not quite straight and winds in a long spiral round the intestine. In the course of development it becomes converted into a strong ridge projecting into the lumen of the intestine. The spiral it makes becomes much closer and it thus acquires the form of the adult spiral valve. A spiral valve is also found in *Chimæra* and no rudiment of such an organ is found in the Teleosts, the Amphibia or the higher vertebrates.

The distribution of the spiral valve among the Craniates offers certain interesting peculiarities. In the *Petromyzontia* the long straight intestine has a slightly spiral valve and it is universal in *Condrichthys* where it may assume a complex infolding of the intestinal wall provided with blood vessels and increasing the absorptive surface. It is already much reduced in *Amia* and *Lepidosteus* and it has disappeared from the intestine of all the living Teleostei except *Chirocentrus*. Vestiges of it may perhaps remain in some *Solmonidæ* and *Gymnarchus*. With the disappearance of the spiral valve the intestine becomes greatly lengthened and much coiled. It is obvious that the function fulfilled by the spiral valve, *viz*., increasing the absorptive surface and impeding the far too rapid progression of food is now assumed in all forms with a long coiled intestine by the midgut itself.

T. J. Parker[13] in discussing the intestinal spiral valve in the genus Raia makes the interesting observation that the spiral valve assumes four chief forms—the simplest known as the Type A with the free edge of the valve at the same level as the attached edge and the width of the valve not greater than half the semidiameter of the intestine, passing through Types B and C to Type D where all the turns of the spiral are deflected forwards and the width of the valve being considerably greater than the semidiameter of the intestine. The variations in the form and disposition of the spiral valve produce a corresponding difference in the amount of the absorption surface possessed by the intestine. In the complicated forms of the spiral valve (Type D of Parker) the absorption surface is greater than that in the less complicated and the resistance offered to the passage of food is immensely increased and consequently the food is exposed for a longer time to the action of the digestive fluids.

In the Elasmobranch *Scyllium canicula* the spiral valve is more highly developed than the most complicated valve in the genus Raia. In *Notidanus*, *Cestracion philippi* and *Chimæra monstrosa*, a spiral valve of varying degrees of complexity is present but in *Zygæna malleus* and *Carcharia lumensis* the intestine possessed what is described as a scroll valve. The fixed free edge of the fold of the intestinal wall runs straight and parallel with the axis of the intestine and the fold itself is 'rolled upon itself into a cylindrical spiral'. In *Lepidosiren* and *Ceratodus* we have spiral valves resembling Type B of Parker. Lastly in the Lampreys a ridge of mucous membrane projects into the intestine and takes the course of an open spiral. The width of the valve is not more than half of the diameter of the gut. The valve is Lamprey therefore of the simplest type—far simpler than Type A of Parker. A valve of this sort is to all intents and purposes a typhlosole differing from the latter only in its spiral instead of a straight course.

The spiral valve of the fishes reduced to its simplest type would be a typhlosole and the scroll valve of some Elasmobranchs infinitely reduced to width resolves itself to the same structure. Thus the more complicated spiral and scroll valves of the fishes are to be derived, according to T. J. Parker,[13] from a comparatively simple longitudinal typhlosole. The following diagrammatic representation would enable us to grasp the idea.



The degree of complexity attained is judged by the extent of the absorptive surface developed and the degree of resistance offered to the passage of the intestinal contents.

In the light of these observations the occurrence of a straight non-spiral ridge reaching about three-fourths of the diameter of the pre-rectal region of the intestine confers on the animal a very remarkable archaic character. In addition to the development of the additional structure being a primitive feature, even the fully developed structure is far more primitive than similar structures found in fishes. The existence of the typhlosole in the turtle, it seems to me, is a remarkable case on record of spontaneous variation in nature. The structure is neither rudimentary nor a comparatively useless nor merely an ornamental one. The perfection of this organ is of the highest importance to the animal's well-being, judged in the light of the animal's diet and other interesting morphological features of the digestive tract.

Balfour[1] further observes that "the presence of this peculiar organ appears to be a primitive vertebrate character. The intestine of the ascidians exhibits the same peculiarity as that of Ammocœtes and we may probably conclude from embryology that the ancestral chordata were provided with a straight intestine having a fold projecting into the lumen to increase the area of intestinal epithelium.

"In all forms in which there is not a spiral valve with the exception of a few teleostei, the intestine becomes considerably longer than the cavity which contains it and therefore more or less convoluted."

These observations of Balfour[1] read in conjunction with those of Owen[11] and Parker[13] already referred to will require an explanation as regards the intestinal structure of *Emyda vittata*. In a specimen whose carapace measured 9 inches, the alimentary canal without the œsophagus is slightly more than 5 times as long and the midgut is thrown into 6 or 7 transverse folds held firmly by folds of mesentery loaded with fat. In *Emyda vittata*, the exceedingly long intestine, which is an advanced character, possessing a well-developed longitudinal ridge, obviously a primitive feature, is an apparent anomaly, which can be explained on the basis of the Doctrine of Definite Direction in Evolution. The short straight intestine and a spiral valve are correlated parts of a system distinctly primitive and if in the course of evolution of the higher vertebrata, the intestine were to assume greater length fulfilling the functions of a spiral valve, the latter must necessarily and gradually disappear as is traceable through the Ganoid and Teleostean fishes. If however, as a result of adaptive modification produced by the peculiar feeding habits, the typhlosolar ridge were to reappear, it does not follow that the intestine also should become correspondingly short,—in fact it will be contrary to the requirement necessary for the establishment of the theory of Definite Direction in Evolution. Among the early Palæozoic fishes (Ostracodermi) the dermal armour is correlated with the incipient condition of the vertebral centra. The endoskeleton does not appreciably ossify until the exoskeleton atrophies. If as in the case of Mesozoic fishes (Pycnodontia) the dermal armour were to re-appear, the endoskeleton does not revert to a primitive condition. This phenomenon and other examples point out how when two structures are co-ordinated, one of them coming under the influence of evolution advances in complexity, the other correlated part will tend to disappear, the part that has advanced remains unaffected. This is the Law of Irreversibility of Evolution and a neater example of this cannot be found than the midgut of *Emyda vittata*.

The majority of histological differences are bound up with gross morphological variations such as the types of stomach, presence or absence of pyloric valve and the development of the cæcum.

The distinction between the pharynx and the œsophagus is very marked and the distinction is justified by the differentiation of the longitudinal layer of muscles in the pharynx into an inner and an outer bundle separated by the loose circular layer and the definitely stratified epithelium with a restricted distribution of mucous cells. The epithelial layer of the pharynx resembles the corresponding layer of the buccal mucosa while it differs markedly from that of the œsophagus.

The horny papillæ so common in the marine forms are absent from this reptile. The only possible explanation for its absence is to be found in the nature of the diet of the animal. The marine forms feed chiefly on crustaceans, molluscs and fish and these require to be crushed before they are passed on to the digestive and absorptive seats. But the turtle *Emyda vittata* feeds usually on soft nutriment like the decaying animal and vegetable matter and there is no need for a crushing or a masticatory apparatus. Thus the absence of papillæ is to be accounted for by the soft and succulent nature of the food.

Tullberg[15] writing about the alimentary canal of the Rodents has suggested that the development of the cæcum is related to the diet of the animal which chiefly consists of matter rich in cellulose. As the digestion and absorption of this kind of food depend largely on the duration of its stay in the alimentary tract and as the food passes rapidly through the tract, the cæcal development is an adaptive device for helping the digestion of cellulose. According to Lonneberg[7] the cæcum is largely developed in the herbivorous reptiles and in the herbivorous iguanas a complicated valvular apparatus and a greatly lengthened intestine serve a similar purpose. The turtle forming the subject of this paper feeds on animal dung and other matter poor in nutritious material. The physiological needs of the animal could be satisfied only if the food is retained in the alimentary tract for a long time and thus exposed to the action of the digestive juices. The absence of the pyloric valve and sphincter at the orifices would naturally accelerate the rate of the passage of food through the digestive tract and in order to retard the far too rapid progression of food and to present a larger surface of absorption, the animal has developed a typhlosole.

The existence of discrete spaces between the longitudinal and circular sets of muscles both in the rectal and the prerectal regions, interpreted in the light of the habits of the animal, points to an accessory respiratory function in the intestinal region. The animals when kept under water are seen to take in large quantities of water and the presence of blood vessels in the vicinity of these spaces lends additional evidence of respiratory function.

I have examined besides the commoner reptiles like the local snakes, the crocodile and the rock turtle. The features recorded in the case of *Emyda vittata* are exclusive to the animal.

Histologically the œsophagus and the pharynx are adapted for gustatory and mucous producing functions, enabling the easy and efficient swallowing action. Neither the pharyngeal nor the œsophageal region possesses definite glands nor specialised cells. These regions consequently possess no secretory power apart from mucous production.

Heidenhain[5a] described in 1870 central and parietal cells in the mammalian gastric glands and in 1877 Edinger[5b] found that in the glands of the piscine stomach only the chief or peptic cells occur. In the gastric glands of the turtle the surface epithelial cells are not true mucous cells and the gastric glands consist of cells with granular protoplasm with a central rounded nucleus in the case of the glands of the first type and true mucous cells in the second type of glands. The oxyntic cells are absent in this animal.

Opinion is unanimous that the oxyntic cells do not exist in the fish and Stirling[16a] conceives that the superficial epithelial cells in the fishes perform more than one function. The surface epithelial cells in the stomach of the turtle are not typical mucous-producing cells and as suggested by Stirling[16a] for the fishes, the superficial cells are connected with the production of acid in the turtle stomach during the digestive processes.

SUMMARY.

1. The buccal epithelium is stratified and the buccal glands are absent. A basement membrane is absent.

2. The pharyngeal epithelium is intensely folded and the muscles are extremely well developed. The longitudinal layer is differentiated into an inner and an outer set separated by the circular layer.

3. The œsophagus is differentiated into an anterior and a posterior region, the former characterised by the stratified epithelium with a minimum of mucous cells and the latter liberally beset with mucous cells. The mucosa is intensely folded.

4. In the oesophageal region a well-developed connective tissue sheet in which the muscle layers are embedded is present. The fibres of this sheet run in a direction perpendicular to that of the sub-mucosa.

5. The stomach is very simple and there is no differentiation of the gastric glands.

6. Two types of glands occur—the gastric juice glands and the mucous glands, the latter increasing in number towards the posterior end of the stomach.

7. Three types of cells enter into the constitution of the gastric mucosa—the surface epithelial cells which are not true mucous cells, true mucous cells and the gastric juice cells with granular protoplasm.

8. Oxyntic cells do not occur in the stomach glands of the turtle.

9. There is no pyloric valve between the pyloric end of the stomach and the intestine.

10. The intestinal mucosa is intensely folded in the prerectal region and simulate crypts and villi. Goblet cells are rare and wandering cells occur in large numbers between the surface epithelial cells.

11. The pre-rectal region is characterised by the presence of a longitudinal typhlosole which reduces the cavity of the intestine into a semilunar slit.

12. The development of the longitudinal layer of muscles differs in the different regions of the intestine—feebly developed in the pre-rectal and well developed in the rectal region.

13. Well-marked space lines by cells and with a rich supply of blood capillaries occur between the circular and the well-developed longitudinal layers of muscle in the rectal region.

14. Blood supply to the gut is from three independent vessels arising from the left systemic arch before it joins the right to form the dorsal aorta.

CONCLUSION.

1. The alimentary canal is very primitive in the possession of a typhlosole in the pre-rectal region of the intestine.

2. The existence of this structure is of functional significance for the physiological needs of the animal.

3. The re-appearance of this structure in a vertebrata high in the evolutionary scale affords evidence of a definite direction in evolution.

4. The structure of the intestine with a well-developed longitudinal layer of muscles and discrete spaces with a rich supply of blood capillaries between the muscle layers points to the existence of intestinal respiration.

5. The structure of the gastric glands resembles that of the fish in the absence of the oxyntic cells.

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KEY TO LETTERING.

Bl. v.	Blood vessels.
Cr.	Crypts.
C. M.	Circular muscles.
C. T. S.	Connective tissue sheet.
I. L. M.	Internal longitudinal muscles.
Int. Gl.	Intestinal glands.
L. M.	Longitudinal layer of muscles.
Lum.	Lumen of the gastric gland.
Lym. Nod.	Lymphatic nodule.
M. C.	Mucous cells.
Mus. Muc.	Muscularis mucosæ.
N.	Rounded nucleus of the gastric gland.
Oe. Ep.	Oesophageal epithelium.
M. Gl.	Mucous gland.
G. Ep.	Gastric epithelium.
Sup. E.	Superficial epithelium of the intestine.
Sup. Ep.	Superficial epithelium of the stomach.
Sub. muc.	Sub-Mucous layer.
Typ.	Typhlosole.
W. C.	Wandering cells.
Sp.	Spaces in the thickness of the wall of the intestine.

EXPLANATION OF FIGURES.

FIG. 1. Digestive tract *in situ*.

FIG. 2. Dissection showing the transition of the Oesophagus to the Stomach and the Stomach to the Intestine.

FIG. 3. Transverse section of the buccal mucosa.

FIG. 4. Portion of the pharyngeal wall magnified to show the stratified epithelium. Mucous cells are absent and the musculature is differentiated into external and internal longitudinal bundles separated by the circular layer of muscles.

FIG. 5. Transverse section of the posterior portion of the œsophagus.

FIG. 6. Mucosa of the posterior region of the œsophagus magnified to show the predominance of the mucous cells. Mucous cells found in several layers in the depressions.

FIG. 7. Portion of the wall of the posterior region of the œsophagus showing the epithelium with a predominance of mucous cells, a lymphatic nodule and the muscle layers embedded in a thick layer of connective tissue sheet.

FIG. 8. Longitudinal section showing the stratified epithelium of the œsophagus passing into the superficial cylindrical epithelium of the stomach. X marks the transitional zone.

FIG. 9. Transverse section of the cardiac portion of the stomach showing the long tubular glands closely pressed against each other. The scarcity of the mucous glands is to be noted.

FIG. 10. Photograph of a single gastric gland from the cardiac region showing the narrow lumen lined by cells with a granular protoplasm and a spherical nucleus.

FIG. 11. Transverse section of the gastric mucosa in the middle region. Some of the mucous glands are cut transversely.

FIG. 12. Transverse section of the posterior or the pyloric end of the stomach showing the enormous increase in the number of mucous glands. X shows one of these glands lined exclusively by mucous cells opening into the lumen of the stomach.

FIG. 13. Two villi from the pre-rectal region of the intestine showing the fusion of villi, Leiberkuhn's crypts and numerous wandering cells between the cylindrical surface epithelium.

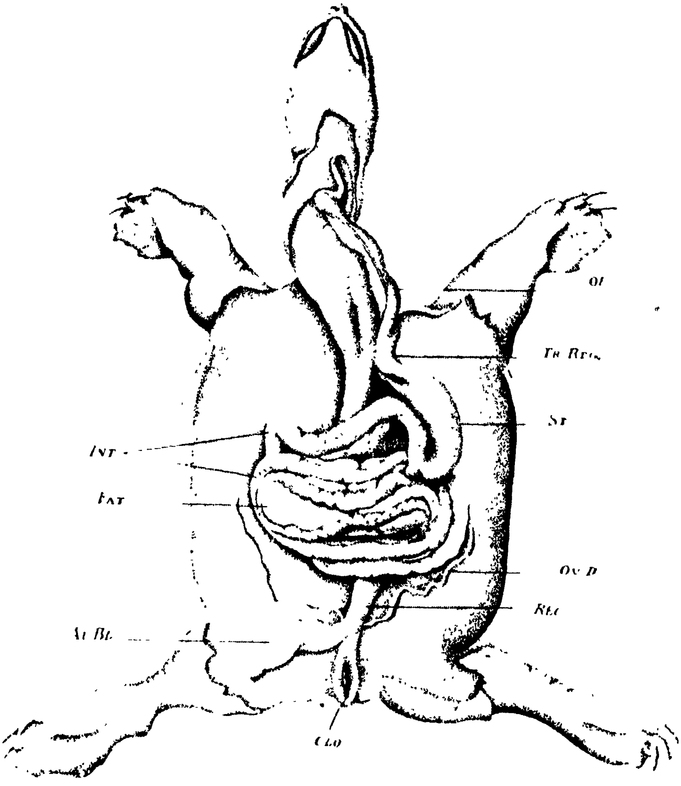
FIG. 14. Diagrammatic transverse section of the intestine showing the typhlosole.

FIG. 15. Portion of the typhlosole magnified to show the connective tissue fibres, blood vessels and the muscularis mucosae.

FIG. 16. Transverse section of the rectal region of the intestine. Portion of the wall magnified to show discrete spaces between the longitudinal and circular layer of muscles, the sub-mucosa and the intestinal glands.

FIG. 17. Glandular region of the intestine magnified to show the intestinal glands in the sub-mucous region and the numerous wandering cells in the epithelial layer.

PLATE I



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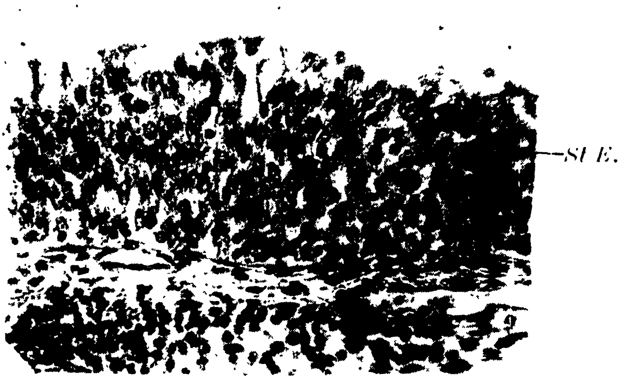
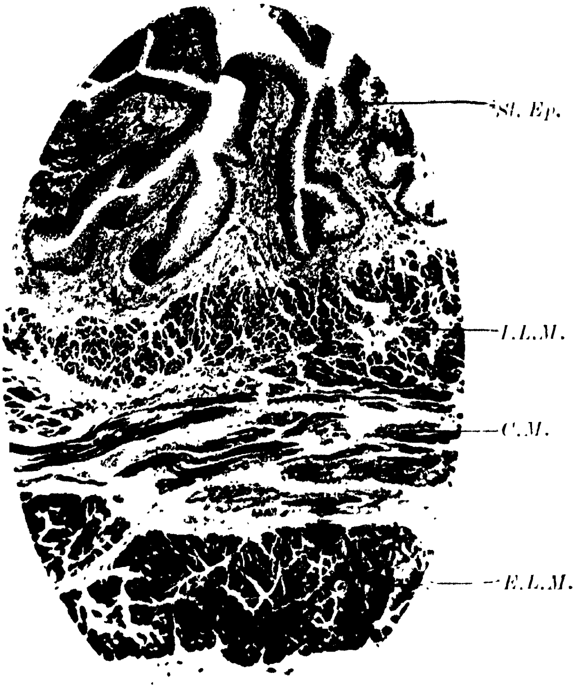


FIG. 3.

PLATE II



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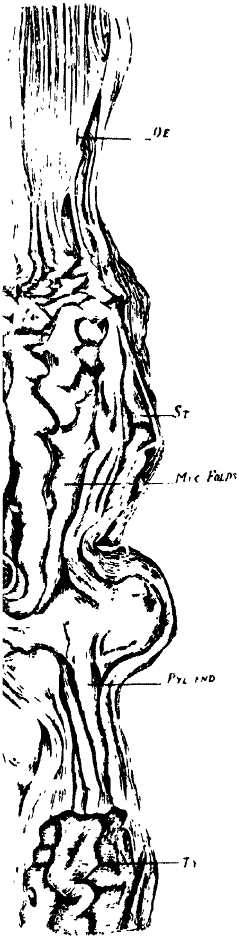

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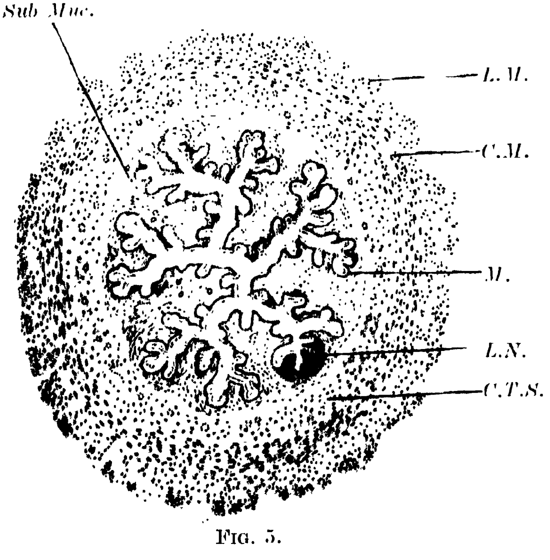
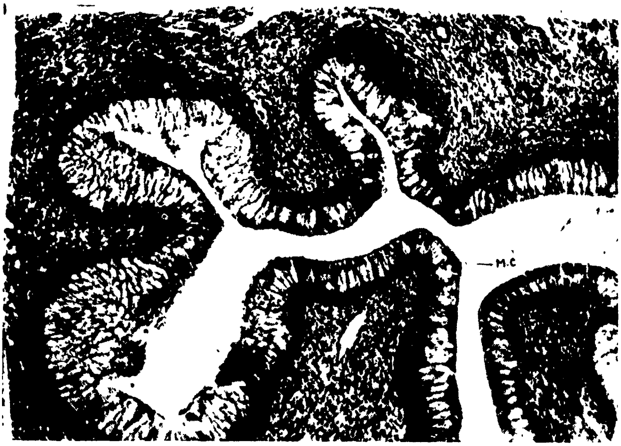


FIG. 5.

PLATE III



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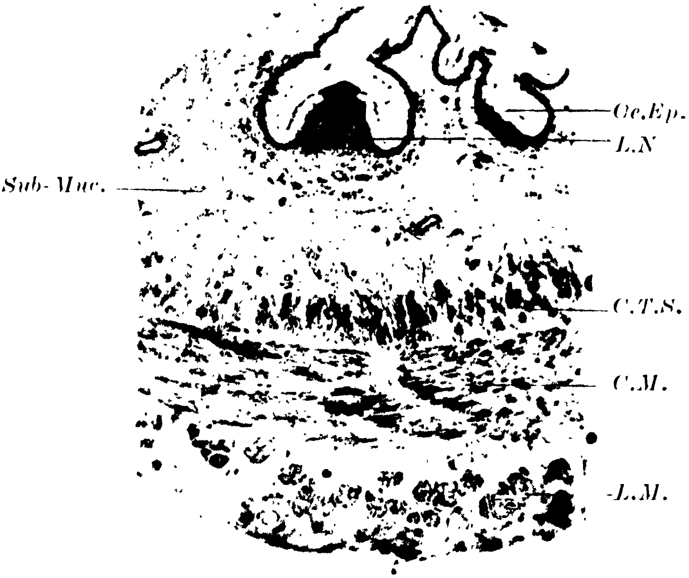
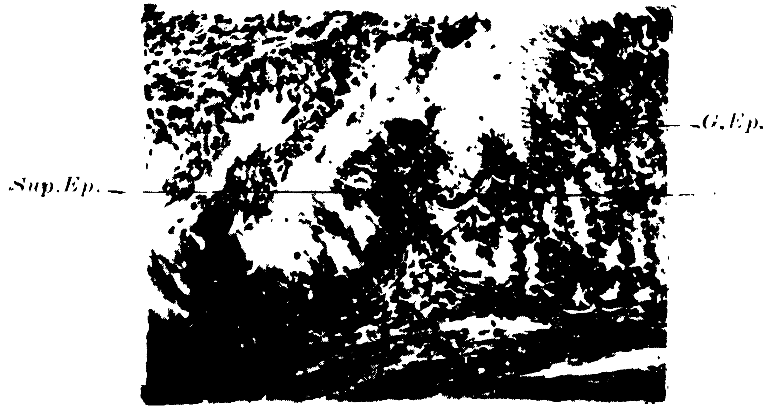


FIG. 7.

PLATE IV



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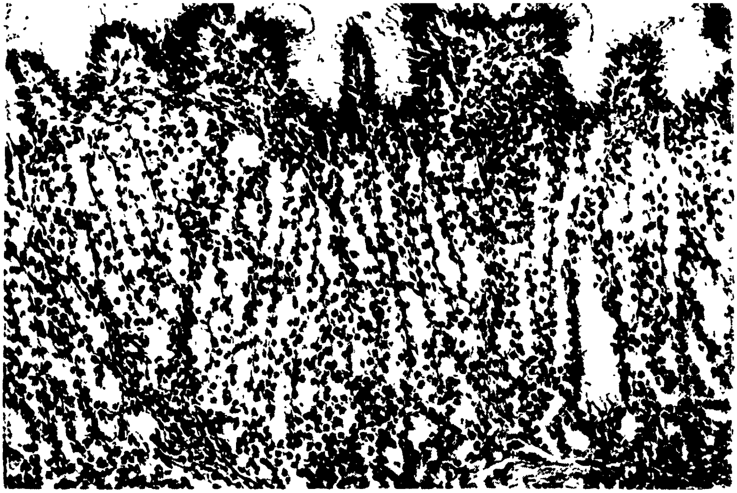


FIG. 9.

PLATE V

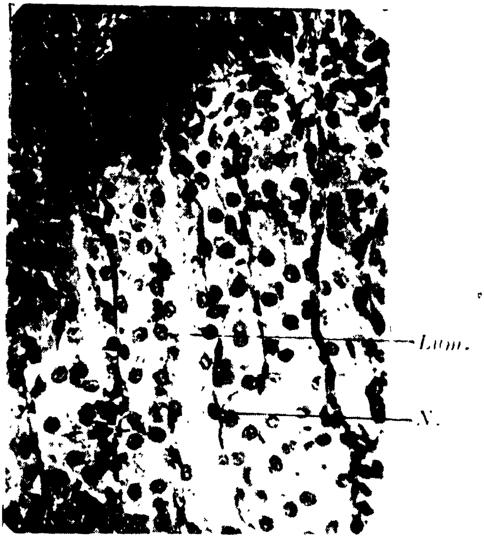


FIG. 10.

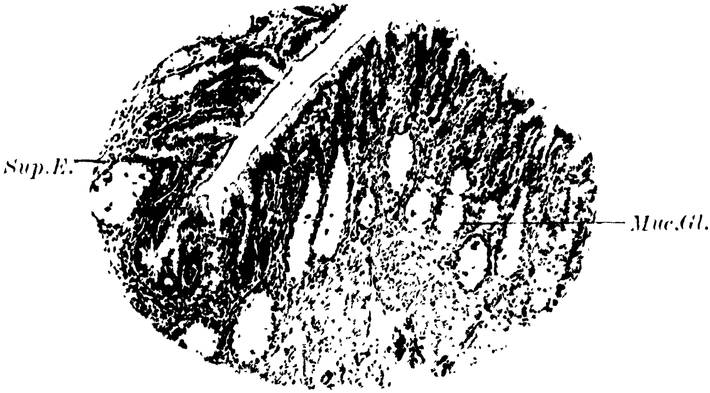
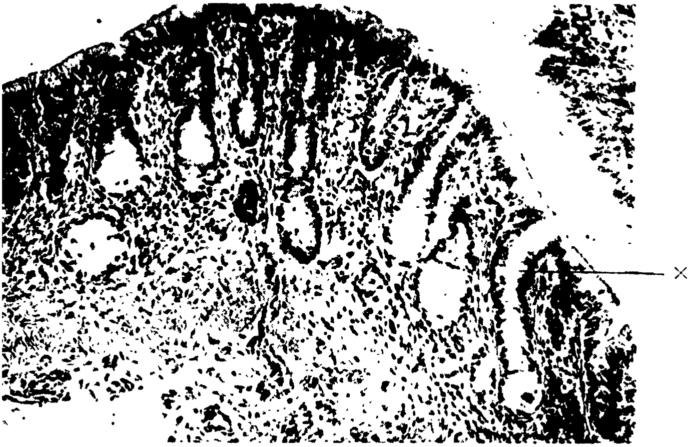


FIG. 11.

PLATE VI



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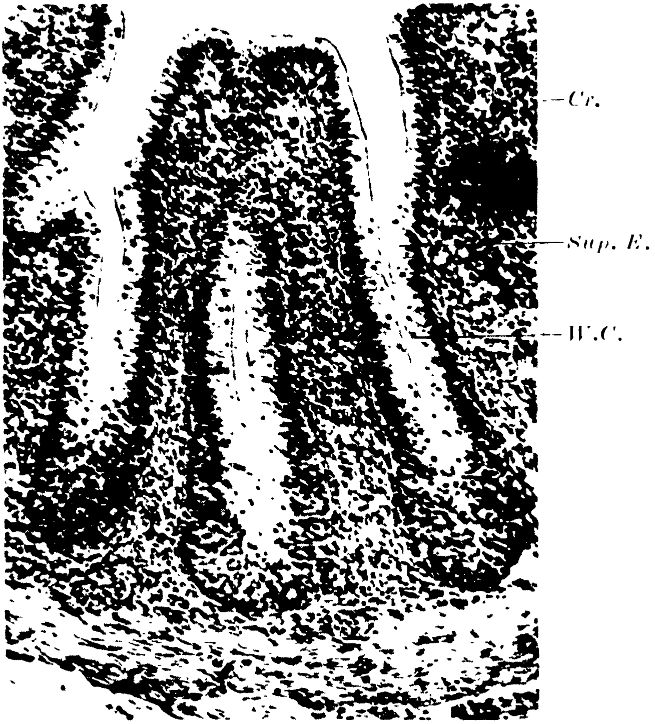

FIG. 13.

PLATE VII

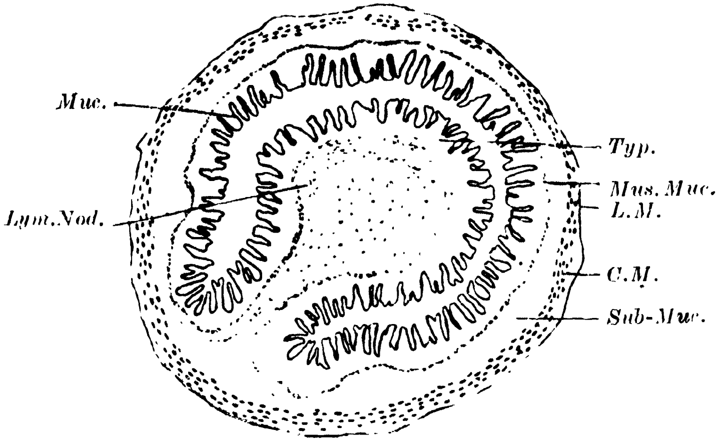

FIG. 14.

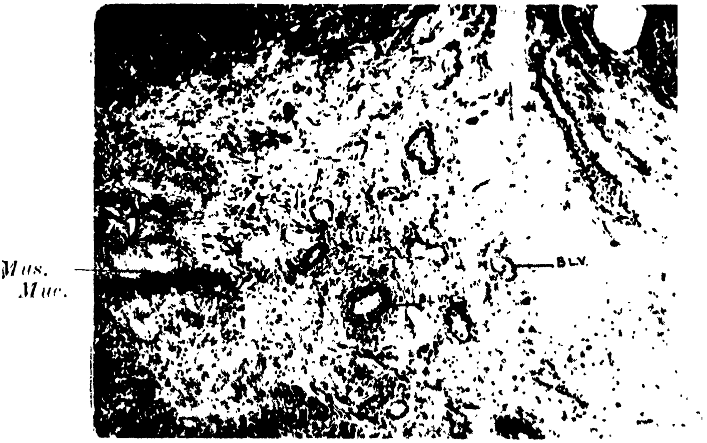

FIG. 15.

PLATE VIII

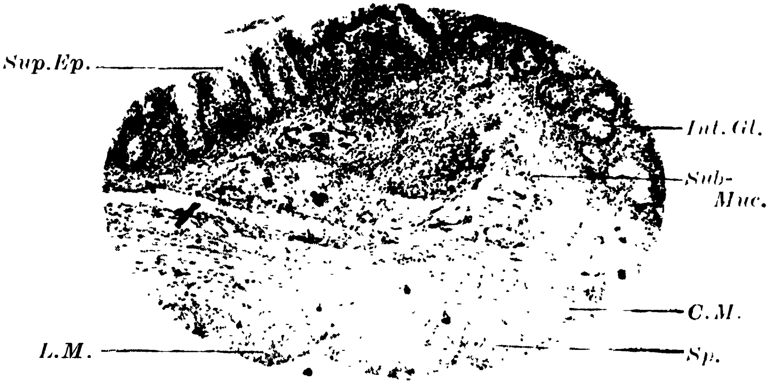

FIG. 16.

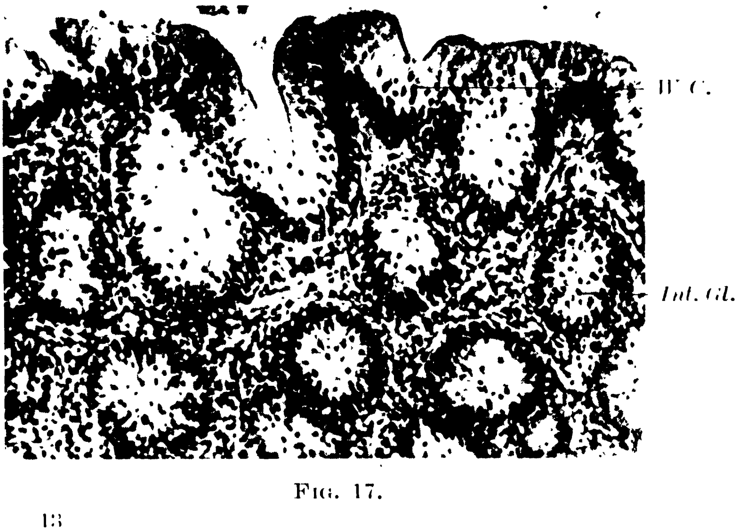

FIG. 17.

THE SPERMATOGENESIS OF *PARATELPHUSA HYDRODROMUS* WITH A NOTE ON OOGENESIS.*

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INTRODUCTION.

The gametogenesis of the crustacea has attracted some attention in recent years and generally cytologists have confined themselves to the behaviour of cytoplasmic inclusions. Vishwa Nath has recently published his observations on the spermatid and sperm of the crab *Paratelphusa spinigera* and it was suggested to me by Prof. C. R. Narayan Rao, that the behaviour of the nucleus in the spermatogenesis might yield some interesting results.

Concerning oogenesis a preliminary note on the behaviour of the Golgi and mitochondria in this crab was communicated to the Indian Science Congress, 1933, by my colleague Mr. A. Narayana Rao, who subsequently handed over the material to me for further investigation.

In this connection I wish to express my deep debt of gratitude to Prof. C. R. Narayan Rao for his valuable guidance and encouragement in the course of this work and to the authorities of the Indian Museum, Calcutta, for very kindly identifying the specimen sent to them. I should also hasten to thank

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* Thesis submitted in partial fulfilment of the requirements for the M.Sc. degree of the Mysore University.

Mr. A. Narayana Rao, for placing at my disposal unreservedly the material used in his investigation.

PREVIOUS WORK.

Considerable work has been done on the Decapod spermatogenesis particularly on the genesis of the spermatozoa. The interest in the crustacean spermatogenesis is centred in the fact that the crustacean sperm unlike that found in other animals belongs to the type commonly described as the radiate type.

Gilson,[10] Grobben,[11] Hermann[17] and Sabatier[26,27] have given excellent accounts of the genesis of the spermatozoa in crustacea including such forms as *Astacus fluviatilis*, *Pagurus striatus* and such other crustaceans.

Grobben[11,12,13] first described the spermatozoan of Stomatopoda and gave a brief description of the development of the spermatozoan. The spermatid has a spherical nucleus enclosing a number of nucleoli and surrounded by a faint granular cytoplasm. In the formation of the sperm the nuclear substance concentrates towards one pole of the nucleus where the future head of the spermatozoan develops, and takes a crescent shape. The substance next concentrates to form a hemispherical body which becomes homogeneous and refractive.

The early workers paid special attention to the origin of the spermatogonia or "protospermatoblasts" (Sabatier[26,27]), but Gilson[10] made a comparative study of the crustacean spermatogenesis and confined himself in the main to the development of the spermatogonia and the metamorphosis of the spermatid into the spermatozoa.

Labbe's[20,21] work on the spermatogenesis of *Homarus*, *Palinurus*, *Stenorhynchus*, *Carcinus* and other crustacea contains some very interesting observations not only as regards the behaviour of the nucleus during the maturation divisions that succeed each other very rapidly but also the behaviour of the cytoplasmic inclusions like the mitochondria. In the process of sperm formation a vesicle appears opposite the spermatid nucleus and the shape of the former varies with the species. The cytoplasm proper forms the radiating arms which arise round the nucleus. Mitochondria persist as the internal vesicle.

Nichols[24] described and figured the spermatozoan of Squilla and several other crustaceans.

Nathan Fasten[3] in his paper on the spermatogenesis of the American crayfish, *Cambarus virilis*, states that he could distinguish primary and secondary spermatogonia with the spermatogonial complex of 124 chromosomes. He further observes that there is no rest period between the primary and secondary spermatocytes and reduction takes place in the first division. He further encounters four kinds of spermatozoa distinguished by three, four, five and six rays.

The behaviour of the cytoplasmic inclusions in crustacean oogenesis has formed the subject of investigation by King,[18] Nath,[29,30] and Harvey.[14,15,16] The findings of these authors show that even in forms closely related to each other the behaviour of these inclusions shows remarkable variations. King[18] observed that in the Isopod *Oniscus* there is no nuclear activity. The mitochondria swell and give rise to albuminous yolk directly and the Golgi in a similar way forms fatty yolk.

Harvey[15] working on the oognesis of the marine crab *Carcinus mænas* states that the albuminous yolk arises in relation with the Golgi and probably is deposited in the chromophobe part thereof under the influence of the former; later, material of nucleolar origin is added on to the yolk droplets.

Recently Vishwa Nath and Desaraj Mehta[33] in their paper on the studies in the origin of yolk find that in the prawn *Palæmon lamarrei* the albuminous yolk arises in relation to the mitochondria and the Golgi bodies influence the formation of the fatty yolk. They record further that the nucleolar extrusions in the form of basiphilic pieces are seen in the cytoplasm and their subsequent behaviour does not warrant the hypothesis of their association with the formation of the albuminous yolk. In the crab *Paratelphusa spinigera*, mitochondria remain inactive and have no visible relationship with albuminous yolk which arises in association with well-marked nucleolar extrusions.

MATERIAL AND METHODS.

The freshwater crab *Paratelphusa hydrodromus* was obtained from tanks in and around Bangalore. The gonads were in many cases dissected immediately after their arrival and the other crabs were kept by in porcelain sinks containing freshwater which was frequently changed and were dissected at different intervals.

The testes were dissected in normal saline water and after being cleaned carefully of the sticking hepatopancreas they were immediately transferred to the fixatives. The material required for studying the behaviour of the Golgi and mitochondria in spermatogenesis consisted of smear preparations also. The smears were made on clean slides and were immersed in jars containing Champy, Flemming-without-acetic and strong Flemming from one to two hours and washed in running water for 20 to 30 minutes. They were mordanted in the usual way and stained with Shortt's Iron Hæmatoxylin. For sectioning, the material was fixed in Bouin's Picroformol acetic with 2 and 4 per cent Urea from 4 to 8 hours and was imbedded in paraffin after gradually grading through alcohols and cleared in cedar-wood oil. The sections were cut 5 to 10 microns in thickness. The sections were stained with Shortt's Iron Hæmatoxylin and in all cases the results have been very satisfactory.

The ovaries were dissected in normal saline water and after being cleaned of the sticking hepatopancreas they were cut into small bits and transferred to the fixatives immediately. Numerous fixatives for sectioning the material were tried and Bouin's Picroformol employed from 4 to 8 hours has yielded very good results. For mitochondria the material was fixed in Gatenby's modification of Flemming for 24 hours and washed in running water for 24 hours. The material after grading through alcohols and cleared in cedar-wood oil was imbedded in paraffin and sections 7 to 10 microns in thickness were cut and stained with Shortt's Iron Hæmatoxylin. Mann-kopsch and Nassanov have given successful preparations of Golgi.

GENERAL MORPHOLOGICAL NOTES.

The male reproductive organs of *Paratelphusa hydrodromus* lie in the cephalothoracic region. They consist of a bilobed tubular testis one running on either side and lying over and surrounded by hepatopancreas and a pair of long convoluted vasa deferentia. Each lobe runs laterally and directly below the anterior region of the heart and the testicular lobes unite and from this point the convoluted vasa deferentia originate. The male ducts run posteriorly and open on the ventral surface at the base of the third thoracic appendage.

The ovaries are similarly situated and form a typical cross. Anterior to the region of the heart the limbs of either side are connected by a transverse bar. Posteriorly the ovaries are associated with glandular structures situated just near the external opening. The female opening is on the ventral surface situated in the centre of the last thoracic segment.

SPERMATOGONIA.

In examining the testicular lobe it is found that cells of different stages of development are seen from the anterior to the posterior end. The lobes are arranged in definite regions. I have not succeeded in finding different stages within the same locule. In the anteriormost regions I find cells undergoing rapid multiplication and the spermatogonia are confined to the lobes in this region while towards the posterior ends and in the vasa deferentia I find fully formed spermatozoa.

GROWTH PERIOD AND MATURATION.

In my preparations I have succeeded in distinguishing the primary and secondary spermatogonia although the distinction between the two is not very marked. The sections as well as the smear preparations reveal the presence of a distinct vacuole within the nucleus of the primary spermatogonium (Fig. 2), a feature which has not been so far recorded though the presence of such a vacuole is of common occurrence in the spermatid prior to its metamorphosis into the spermatozoa. (I understand from Mr. B. R. Seshachar that he has noticed such a feature in the preparations of the testis of *Ichthyophis glutinosus* which he is investigating.) The secondary spermatogonia are restricted to the active proliferating region. Apart from the topographical distinction the two kinds of spermatogonia differ from one another by the nature of the nucleus. The nucleus of the primary spermatogonium is large and vesicular and possesses a distinct nucleolus and the chromatin is clumpy and shows a peripheral distribution (Fig. 1), while in the secondary spermatogonium the nucleus is more rounded and the chromatin material is granular (Fig. 2). Even as regards size, the primary spermatogonia are twice as large as the secondary ones. The cytoplasm in both the primary and secondary spermatogonia is uniform. During the multiplicative period the spermatogonia enter upon the phases of division and the chromatin of the nucleus fragments and ultimately heavily staining clumps of chromatin appear (Fig. 4). The nuclear wall soon breaks down with the result the cell enters the metaphase stage of division (Figs. 14 and 15). Polar views of the metaphase plate show a number of chromosomes which are rather small and numerous (Fig. 16). It is not easy to determine the diploid number in the spermatogonial divisions, but as I have successfully determined that there are 55 bivalent chromosomes in the primary spermatocyte, I take it that the spermatogonial count is 110. This is followed by the growth of the spermatogonium into the spermatocyte.

The resting spermatocyte is slightly smaller than the secondary spermatogonium. Within the spermatocyte nucleus could be seen numerous irregular clumps of chromatin distributed over a network of linin threads. An early indication of development in the primary spermatocyte is seen in the nucleus. The chromatin generally fragments and weaves out into a number of threads. The threads are so numerous that it is not possible to count their exact number.

I have not been able to observe any definite orientation of leptotene threads nor have I succeeded in tracing the synaptic phenomenon. Nathan Fasten[5] describes in *Lophopanopeus bellus* the pachytene stage in which the leptotene threads pair thereby transforming them into distinct gemini. The absence of well marked zygotene and the pachytene stages must account for the absence of the definite orientation of the leptotene threads. In my preparations the leptotene condition is followed by a stage in which the leptotene threads draw together to form the first contraction figure of Wilson[34] or "Synizetic knot" (Fig. 7). The intensely staining knot is confined to one pole of the nucleus leaving a clear space towards the other pole. The synizetic knot stage is accompanied by a stage in which the knot opens out to give rise to groups of deeply stainable knots and emerging from each of these knots could be seen short, stout threads which undoubtedly represent the fused leptotene threads. I could not determine the precise procedure by which the tetrads are formed. I shall confine myself to a few remarks on Figs. 5 and 6 which represent the nucleus in the diakinesis stage. In the figures referred to above, the nucleus shows several figures many of which are in the shape of V's and U's and in both these figures I could make out a double cross occupying precisely the same position in both the cases. The limbs of the V's and U's are seen at different angles probably as a result of the opening out of the longitudinal halves. These observations, fragmentary as they are, suggest that the formation of the tetrads in this animal is more complicated than in other crustaceans described by Nathan Fasten. By this stage the nucleus has attained its largest volume and the chromosomes are characteristically distributed round its periphery immediately beneath the nuclear membrane. The nuclear membrane disappears and the chromosomes lie in the cytoplasm. The tetrads soon condense into rod-shaped chromosomes and the nucleus has now entered upon the metaphase period of the first division (Figs. 12 and 13). The bivalent dumbbells now line up the equatorial plane and from either ends of the chromosomes, converge towards the poles, delicate spindle fibres. Fig. 17 would represent the bilateral view of the metaphase plate. The anaphase and telophase follow quickly ultimately producing the secondary spermatocytes. The division of the secondary spermatocytes is equatorial. The cells are on the whole half the size of the spermatocytes and as I have not observed in my preparations the occurrence of the chromatoid body only one kind of spermatid is formed.

The second spermatocyte division is followed by the grouping of chromosomes towards the end of the spindle. The chromosomes are so closely grouped together that they generally form a compact chromatin mass. The spermatid is a rounded body with a spherical nucleus. Soon, however, a clear space appears within the nucleus and gradually a few other similar spaces are formed until the nucleus exhibits a reticular nature. Fasten in the spermatogenesis of the crab does not refer to a vacuole of this kind within the nucleus but describes a disintegration of a dense chromatin of the nucleus. The disintegration according to this author is so consistent that this is ultimately represented by granules appearing like karyosomes. In my preparations as a result of the development of the vacuoles the nucleus presents a reticular appearance and loose consistency. The nucleus maintains this reticular appearance for a fairly long time. While these changes are taking place in the nucleus a vacuole appears at one end of the cytoplasm and the nucleus is pressed towards the opposite pole (Fig. 24). Simultaneously with these changes mitochondrial vacuoles make their appearance and a running together of the mitochondria takes place.

TRANSFORMATION OF THE SPERMATIDS INTO SPERMS.

Gilson[10] who has made a comparative study of the spermatogenesis of the crustacea has given a correct genesis of the transformation occurring in the spermatids in the formation of the sperm. However, he confines his observations to the behaviour of the nucleus and makes no mention of the rôle of Golgi and mitochondria in the formation of the sperm. The development of the vacuole pushes the nucleus to the pole of the spermatid where the former undergoes various changes of form. The contents of the nucleus lose their staining power and present a homogeneous appearance. According to Fasten the process is almost identical with that described by Gilson and the mature sperm is the result of the following components which take an active part in the spermateleosis :—

(*a*) A transparent vesicle originating in the cytoplasm of the spermatid.

(*b*) Radiating arms produced from the rest of the cytoplasm and found along thin strands derived from the centrosome.

(*c*) The compact nuclear mass situated at the bottom of the cytoplasmic cup.

In his paper on the spermatogenesis of the black clawed crab, Nathan Fasten describes the changes in the nucleus bringing about a gradual disappearance of the chromatin masses till ultimately only one body which may be a nucleolus resembling a karyosome is left within the nucleus. *Pari passu* with these changes a densely staining mass makes its appearance in the cytoplasm. This mass identified by Koltzof[19] and Binford[1] as mitochondria, Fasten regards as chromatin which has diffused out of the nucleus. He describes that the cup which encloses the vacuole developed in the cytoplasm is nucleomitochondrial in nature. A second vacuole appears within the first and Fasten accounts for the development of the secondary vacuole as a result of diffusion of a substance from the distal end of the central rod which represents the fused centrosome and the karyosome-like body of the nucleus. This second vesicle gradually increases in size and fits compactly into the first. The radial arm originates from the nucleomitochondrial cup. Nath[31] in his recent contribution to Decapod spermatogenesis says that the only paper on the spermatogenesis of the crab makes no mention of the acrosome and the Golgi and comes to the conclusion based on his observations on the sperm formation of *Paratelphusa spinigera*, that the nucleomitochondrial vesicle of Fasten is nothing but the cup formed by the fusion of the nucleus and the acrosome while the primary vesicle of Fasten is a vacuole formed by the running together of the mitochondrial vesicles, and the secondary vesicle is produced by the centrosome.

My observations on the spermateleosis of *Paratelphusa hydrodromus* are in accord in all essential respects with those of Nath but the changes that take place within the nucleus of the spermatid shows certain minor variations.

At the end of the second spermatid division the chromosomes group themselves at the sides of the spindle. The chromatin masses form a compact nucleus. The spermatid is a rounded cell with a completely compact deeply staining nucleolus. Towards one pole of the nucleus I can make out granular mitochondria (Fig. 29) and about the same region, in Champy preparations is to be seen a deeply stained body in which could be made out ring-like structures. This represents the Golgi bodies which have run together to form a compact body the acrosome. Besides in smears made by Bouin's fluid and stained with Iron Hæmatoxylin could be seen a deeply stained granule in the cytoplasm which is a centrosome. In this connection it must be remembered that the centrosome makes its first appearance in the spermatid and cannot be detected in the earlier stages of spermatogenesis.

In the early spermatid with a compact deeply staining nucleus a vacuole makes its appearance within the former with the result that the deeply staining cuticle and a lightly staining medullary area could be made out. The peripheral staining area gradually increases and reduces the lighter area till ultimately the nucleus becomes a darkly staining body occupying a pole of the cell. While these changes are taking place the centrosome divides into two and travels towards the nuclear end.

The mitochondria which in the earlier stages are in the form of bubbles and vesicles run together to form a distinct vesicle which corresponds to the primary vacuole of Fasten. The development of the mitochondrial vesicle pushes the nucleus to a pole opposite to that in which the vesicle is developing. A few are left over and do not share in the formation of the vesicle and even in the later stages of the spermatogenesis they are to be seen lying towards the base of the developing sperm.

While these changes are taking place one of the centrosomes places itself between the mitochondrial vesicle and the nucleus and the acrosome which is situated towards the nuclear region expands into a band and rapidly develops the basal part of the mitochondrial vesicle like a ring. A careful examination of this ring even at this stage shows the presence of vacuoles within it. Figure 27 shows a stage where one can make out the mitochondrial vesicle with a deeply staining band surrounding it towards the basal region and the nucleus which has assumed the shape of a cup. The distinction between the acrosomal ring and the nucleus is soon lost resulting in the fusion of the acrosome and the nucleus and in the ripe spermatozoa the two cannot be distinguished. Simultaneously with these changes the distal centrosome makes its way into the mitochondrial vesicle and gradually develops a vacuole within the primary one and corresponds to the secondary vesicle of Fasten but is centrosomal in origin.

Soon a thin line grows out from the distal centrosome and penetrates the vacuole formed by the proximal one (Fig. 28). The basal region is seen to be surrounded by a cup-like structure. Following these changes the nucleo-acrosomal cup develops into a complete ring-like structure drawn up tightly round the mitochondrial vesicle. At the distal end the axial filament which has pierced the mitochondrial vesicle shows towards the distal end a small deeply staining transverse piece (Fig. 28). This transverse piece, suggests Nath, might supplement the function of the ring-like centrosome, that of keeping the mitochondrial vesicle well pressed into the nuclear acrosomal cup.

The fully formed spermatozoan (Fig. 29) is a complete disc when viewed from the bottom. The margin of the disc is formed by deeply staining fused nucleus and acrosome. The lightly staining area enclosed by this ring would represent the mitochondrial vesicle while the centre is occupied by the proximal centrosome with the deeply staining granule, the axial filament.

BEHAVIOUR OF THE CYTOPLASMIC INCLUSIONS IN OOGENESIS.

In the young oocytes the nucleus is very large and vesicular. Surrounding the nucleus are to be seen a number of mitochondrial granules (Fig. 32). Soon after the oocyte has differentiated from the germinal epithelium a cloud which stains deeply with Iron Hæmatoxylin appears all round the nucleus. Towards the pole from which a first peripheral scattering takes place there is a great concentration almost in the form of a conical cap (Fig. 33). The mitochondria are stained black in Flemming-without-acetic and followed by Iron Hæmatoxylin. In the Mannkopsch unstained preparations the same distribution is observed. At this stage the oocyte does not show any traces of yolk either albuminous or fatty. With the peripheral scattering of the mitochondria the albuminous yolk makes its appearance. Various growth stages of this could be seen from the centre to the periphery of the oocyte (Fig. 34). During this process the mitochondria swell and give rise to albuminous yolk. In the full-grown oocyte the albuminous yolk is of mitochondrial origin and is seen as yellow platelets surrounded by clear space.

Both the Mannkopsch and the Da Fano methods failed to reveal the Golgi in the germinal epithelial cells. Soon after the oocyte has been differentiated from the germinal epithelium the apparatus appears in the form of a few perinuclear vesicles. With the growth of the oocyte the Golgi vesicles are scattered in the cytoplasm (Fig. 34).

Material fixed in Bouin's fluid and subsequently stained in Iron Hæmatoxylin and counter-stained with Eosin reveals the nucleolus even in very early oocytes as a distinct small body usually eccentric in position within the nucleus. I have not observed more than one nucleolus at any stage of the progress of oogenesis nor have I been able to detect either oxyphilic or basiphilic extrusions of the nucleolus in the cytoplasm. From the early oocytes to the time when the nucleolus is bodily extruded into the cytoplasm it is an intensely basiphilic body never showing any irregularity in its outline. Though it is vacuolated as has been observed by Harvey[14,15,16] and others this phenomenon of vacuolisation does not seem to have any relation whatever either to the fragmentation of the nucleolus or with a change in its staining reactions. The nucleolus shows no change except an increase in size in the whole course of oogenesis.

The researches of King,[18] Harvey[14,15,16] and Nath[30] have established two kinds of yolk, the albuminous and the fatty, the former either mitochondrial or nucleolar in origin and the latter always associated with the Golgi. The mitochondria in my preparations occur in the earlier stages as a cloud of granules concentrated towards one pole (Fig. 33) and with the peripheral scattering of these bodies surrounded by a clear space. The albuminous yolk differs from the fatty yolk, which, as will appear later, arises in relation with the Golgi in certain staining reactions. The Golgi yolk is blackened intensely by Mannkopsch and if Mannkopsch preparations are kept in turpentine the fatty yolk resists decolourisation for many hours while the albuminous yolk is very slightly blackned and yields the colour very early when treated with turpentine. Even as regards the time of its appearance there is considerable difference. The ordinary yolk is seen in my preparations much earlier than the fatty yolk. In older oocytes the fatty yolk is generally concentrated towards the peripheral regions of the oocyte and appear as discreet rounded bodies while the albuminous yolk could be traced from the centre towards the periphery (Fig. 36).

The vesicular Golgi elements increase in number with the growth of the oocyte and show a distinct osmiophilic ring and an osmiophobic centre (Fig. 37). The fatty yolk is deposited within the vesicle under the influence of the osmiophilic part and in the fully formed oocytes the whole vesicle is deeply stained by osmic acid. Thus in *Paratelphusa hydrodromus* the albuminous yolk is mitochondrial in origin while the fatty yolk arises in relation with the Golgi.

Recent studies on crustacean oogenesis have shown that the yolk formation is brought about by one or more of the cytoplasmic constituents, *viz.*, mitochondria, Golgi and the nucleolus. In the majority of animals there is a variation regarding the formation of the albuminous yolk while the fatty yolk is almost always elaborated by the Golgi, though Harvey[16] in the oogenesis of *Carcinus mœnas* makes an interesting observation that the fatty yolk arises *de novo* in the cytoplasm. Desaraj Bhatia and Vishwa Nath[2] on crustacean oogenesis describe the mitochondrial origin of albuminous yolk though definite nucleolar extrusions into the cytoplasm are seen to take place and suggest that in the case of the prawn an indirect contribution of the nucleolus towards the formation of the yolk cannot be ruled out. But in the crab *Paratelphusa spinigera* mitochondria are inactive and do not take part in the yolk formation. The nucleolus in those forms in which it takes an active part in vitellogenesis shows certain morphological changes. In the oogenesis of *Limulus polyphemus*, Mary S. Gardiner[7] describes that rounded protuberances appear on the surface of the nucleolus and material is extruded from them into the cytoplasm. These nucleolar emissions retain a spherical shape within the nucleus and pass into the cytosome as spheres of considerable size. In the cytoplasm each of the extruded material behaves like the parent nucleolus in giving off substances. These extrusions associate themselves with the dictyosomes and form centres of high metabolic activity. In the oogenesis of Scorpions the nucleolus according to Nath[30] buds off deeply basiphilic round bodies in the nucleus. With the growth of the oocyte the nucleolus increases considerably in size and buds off nucleolar extrusions which travel into the cytoplasm as whole bodies through imperfections in the nuclear membrane. In the oogenesis of *Loris lydekkerianus* Narayan Rao[23] suggests that the appearance of the nucleolus is correlated with a certain size of the ovum. It is not present in the tubal eggs and the occurrence of yolk and fat bodies even in the younger ova makes it somewhat difficult to postulate that the nucleolus exerts a direct influence on the formation of the yolk. In the later oocytes before the polarity of the fat globules are established the nucleolus differentiates into the oxyphilic and basiphilic portions. The oxyphilic nucleolus passes bodily through nuclear membrane and after occupying various points in the protoplasm finally it takes a position nearer the cell membrane and in the movements within the cytoplasm these extrusions seem to be the centres around which the fat is deposited. Thus it is clear in all cases where the nucleolus is actively concerned in vitellogenesis the former shows very active movements and marked morphological changes. In my slides prepared by Flemming without acetic and Mann-kopsch technique a number of darkly staining bodies are found in the perinuclear region. There is no reason to confuse these with nucleolar extrusions as these are found in unstained osmic preparations also ; besides during the whole course of oogenesis the nucleolus undergoes no morphological change except an increase in size till finally the entire nucleolus is bodily extruded into the cytoplasm. At no stage have I noticed a differentiation of the nucleolus into the basiphil and oxyphil portions. With the peripheral scattering of the mitochondrial granules albuminous yolk makes its appearance. This fact read in the light of the behaviour of the nucleolus strongly suggests that the albuminous yolk is mitochondrial in origin in *Paratelphusa hydrodromus.*

RÉSUMÉ.

1. Primary and secondary spermatogonial divisions can be distinguished. The spermatogonial chromosomes are numerous and small. The primary spermatocyte undergoes growth and the leptotene stage with a definite orientation of the chromosomes is not observed.

2. The contraction stage is followed by the opening of the knot into three or four groups of thickened chromosomes. This stage is followed by diakinesis.

3. Tetrad formation and reduction division are made out. There are 55 bivalent chromosomes seen in the polar plate of the metaphase of the primary spermatocyte division.

4. The sperm possesses a cup-shaped nucleus, the cup formed by the fusion of the nucleus and the acrosome. The primary vesicle of Fasten is mitochondrial in nature.

5. The proximal centrosome gives rise to the secondary vesicle of Fasten.

6. The sperm in spite of its fantastic form is typical as regards the components that go to form it.

7. The nucleolus does not take part in vitellogenesis.

8. The albuminous yolk is elaborated by the mitochondria and the fatty yolk by the Golgi bodies.

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KEY TO LETTERING.

A.	..	Acrosome.
A. F.	..	Axial filament.
Alb. y.	..	Albuminous yolk.
Chr.	..	Chromatin.
Chr. gr.	..	Chromatin granules.
Cs.	..	Centrosome.
Cy.	..	Cytoplasm.
F. y.	..	Fatty yolk.
G.	..	Golgi body.
G. N.	..	Golgi nucleus. (Nucleus formed by the fusion of Golgi and nucleus.)
M.	..	Mitochondria.
M. V.	..	Mitochondrial vesicle.
n.	..	Nucleus.
nu.	..	Nucleolus.
Vac.	..	Vacuole.

EXPLANATION OF FIGURES.

Fig. 1. Resting spermatogonium with the chromatin distributed in clumps with a prominent nucleolus.

Fig. 2. The secondary spermatogonium where the nucleus is more rounded and granular.

Fig. 3. The spermatogonium with a prominent vacuole in the nucleus.

Fig. 4. The prophase condition of the spermatogonium.

Fig. 5. Spermatogonial mitosis. Polar view of the metaphase.

Fig. 6. Spermatogonial mitosis. Polar view of the metaphase.

Fig. 7. Early Contraction figure.

Fig. 8. Late Contraction figure.

Fig. 9. Breaking up of Synizesis knot.

Fig. 10. Breaking up of Synizesis knot.

Fig. 11. Breaking up of Synizesis knot.

Fig. 12. Diakinesis.

Fig. 13. Diakinesis.

Fig. 14. Side view of Metaphase.

Fig. 15. Side view of Metaphase.

Fig. 16. Polar view of the Metaphase plate showing 55 bivalent chromosomes.

Fig. 17. Late Metaphase.

Fig. 18. Late Metaphase.

Fig. 19. Anaphase.

Fig. 20. Anaphase.

Fig. 21. Telophase.

Fig. 22. Telophase.

Fig. 23. Spermateleosis.

Fig. 24. Spermateleosis.

Fig. 25. Spermateleosis.

Fig. 26. Spermateleosis.

Fig. 27. Spermateleosis.

Fig. 28. Spermateleosis.

Fig. 29. Mature Sperm.

Fig. 30. A young oocyte.

Fig. 31. A young oocyte.

Fig. 32. Oocyte showing mitochondria in the perinuclear region.

FIG. 33. Oocyte showing mitochondrial aggregations at two opposite poles of the nucleus.

FIG. 34. Oocyte showing the distribution of the albuminous and fatty yolk interspersed with Golgi and Mitochondria.

FIG. 35. Oocyte showing a greater distribution of the albuminous and fatty yolk interspersed with Golgi bodies and mitochondria

FIG. 36. Oocyte showing the extrusion of the nucleolus through the nuclear membrane.

FIG. 37. The entire nucleolus bodily extruded into the cytoplasm.

FIG. 38. A portion of the mature oocyte showing the two types of yolk.

FIG. 39. A portion of the mature oocyte with fatty yolk towards the periphery of the oocyte and the albuminous yolk towards the centre.

PLATE I

FIG. 1.

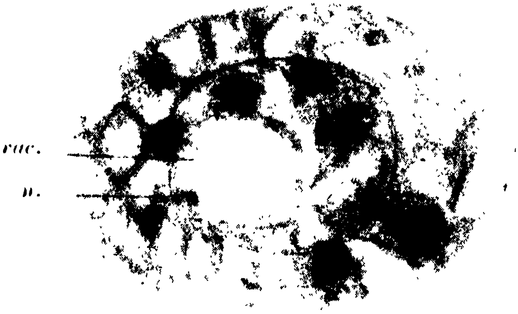


FIG. 2.

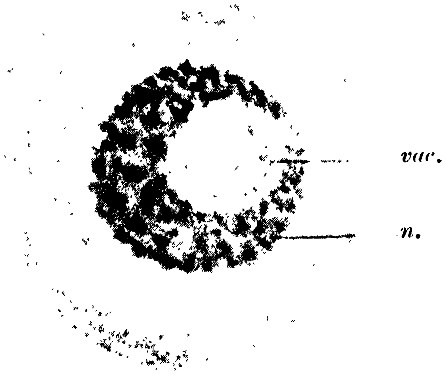


FIG. 3.

PLATE II

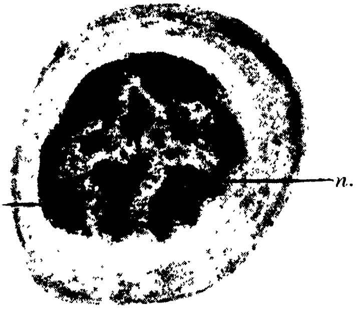


FIG. 4.

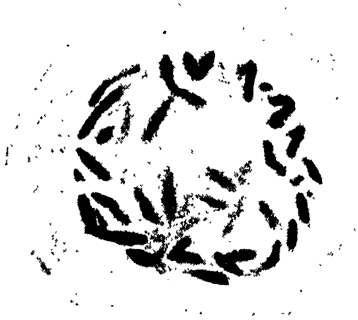


FIG. 6.

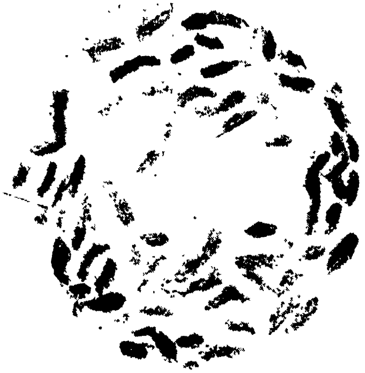


FIG. 5.

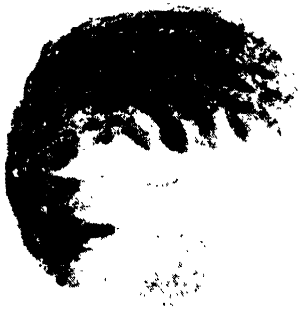
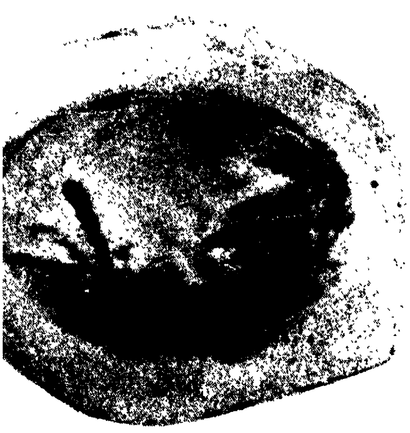


FIG. 8.



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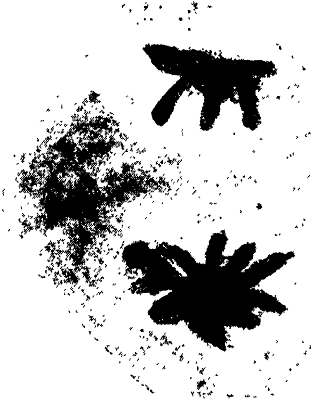


FIG. 9.

PLATE III

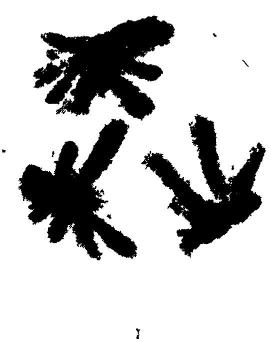
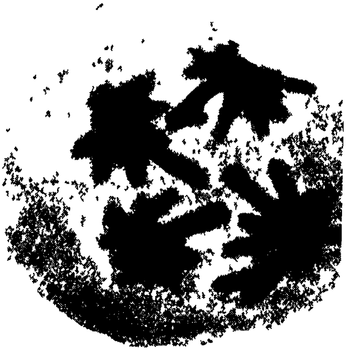


FIG. 10.



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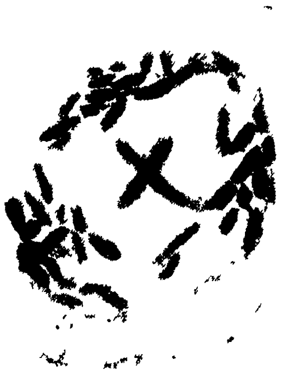

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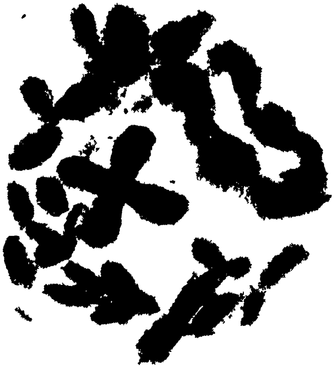

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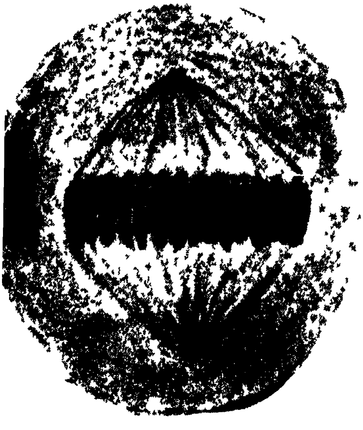


FIG. 15.

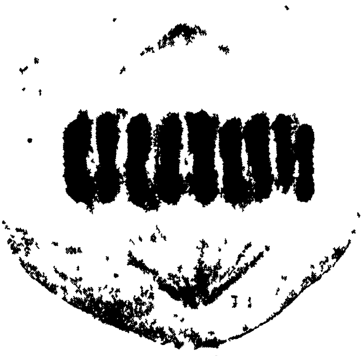


FIG. 14.

PLATE IV

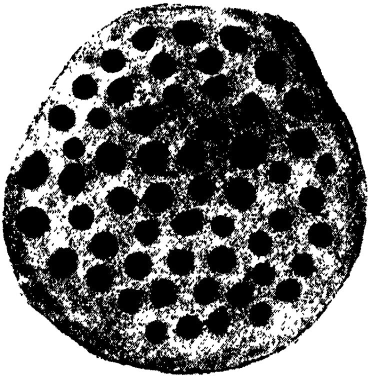
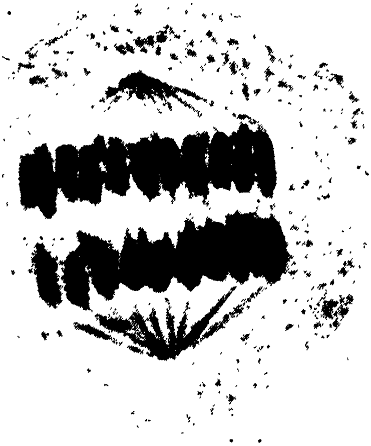


FIG. 16.

FIG. 17.



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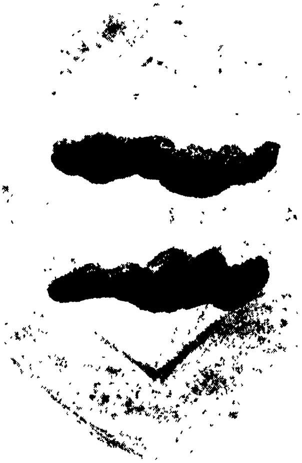
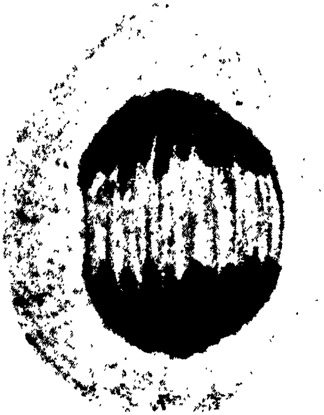


FIG. 19.

PLATE V



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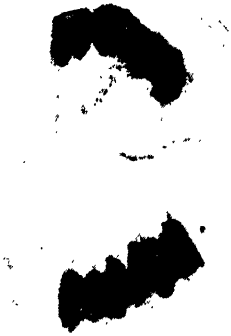

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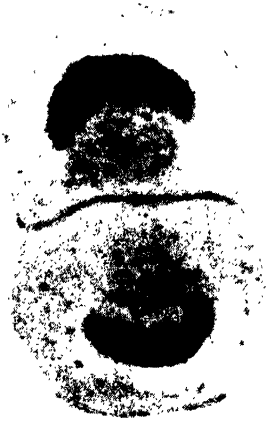

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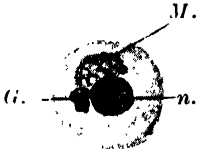

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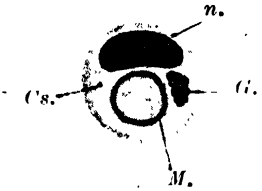

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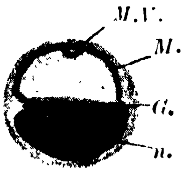

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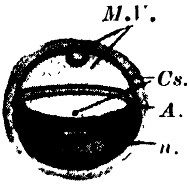

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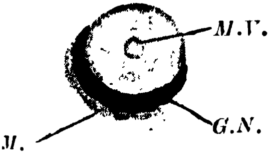

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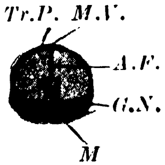


FIG. 28.

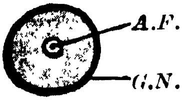


FIG. 29.

PLATE VI

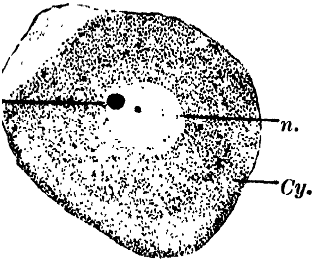
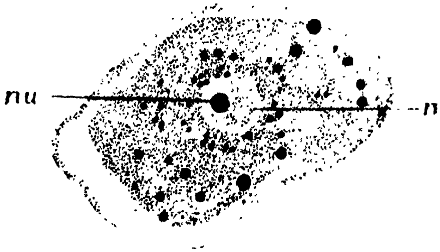


FIG. 30.



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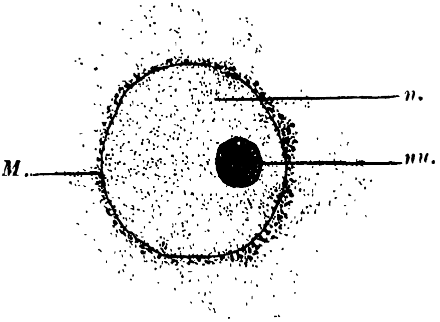


FIG. 32.

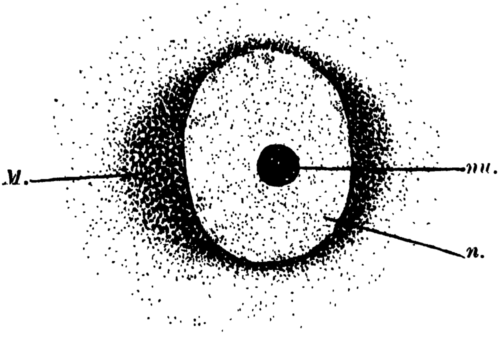
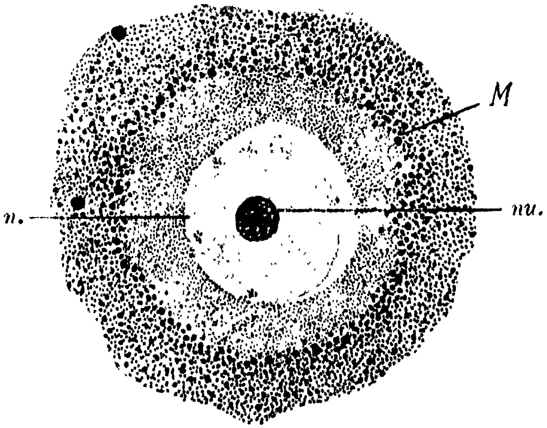


FIG. 33.

PLATE VII



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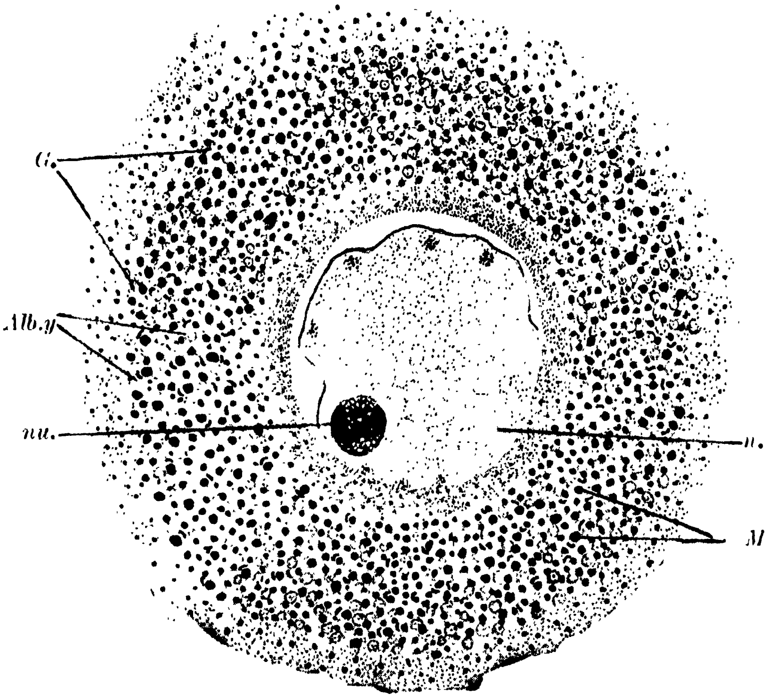

FIG. 35.

PLATE VIII

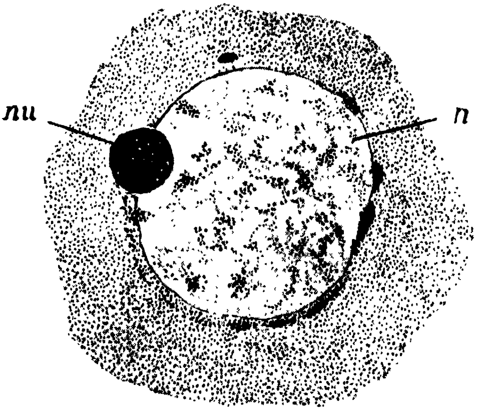

FIG. 36.

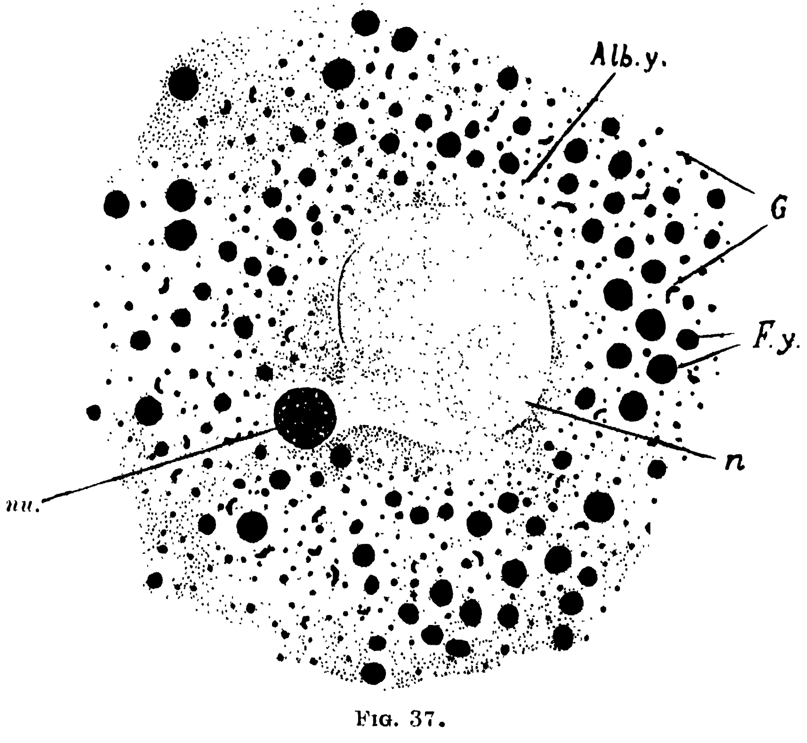

FIG. 37.

PLATE IX

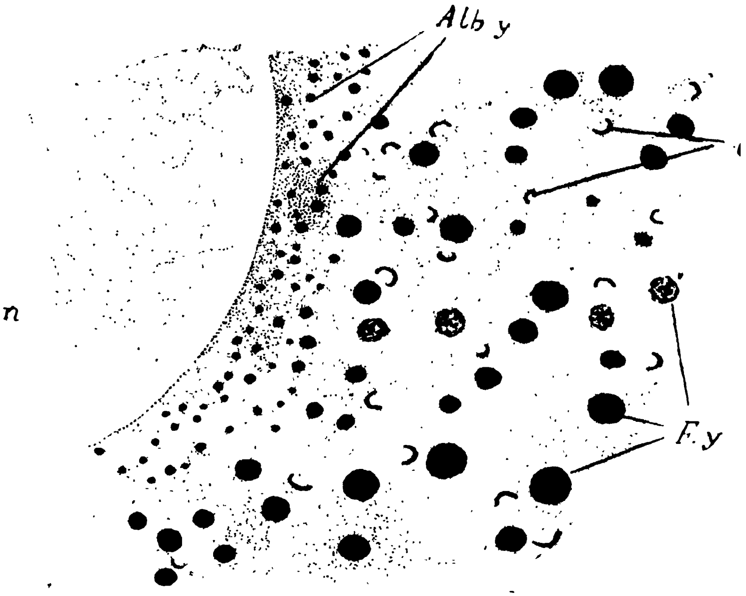

FIG. 38.

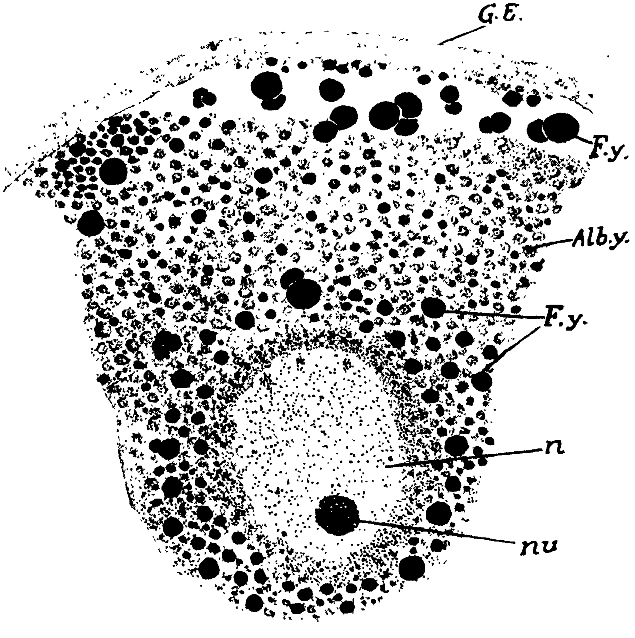

FIG. 39.

ON THE MORPHOLOGY OF THE SKULL OF CERTAIN INDIAN CATFISHES.

BY B. S. BHIMACHAR, M.Sc.
(*Zoological Laboratory, University of Mysore.*)

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INTRODUCTION.

The siluroid fishes form quite a large portion of the Ostariophysi which have undergone very interesting modifications in different directions. Bridge and Haddon,[4] in their monumental work on "The air-bladder and Weberian ossicles in the siluroid fishes" have stated: "It is remarkable that this important group of fishes have so little occupied the attention of morphologists, especially when we take into consideration the interesting modifications which its various members have undergone. . . Probably the main reason why the Siluroids have been neglected is due to the fact that they are principally tropical in habitat, or live in remote inaccessible districts." Catfishes, both freshwater and estuarine forms, are abundantly found all over India. They are rich both in number and variety. During the course of practical work I came across certain very interesting features in the cranial morphology of some of the siluroid fishes, and Dr. B. K. Das suggested to me that this problem, if worked out, would yield very useful results. On perusal of literature available in Calcutta and elsewhere in India it was found that, with the exception of a few papers, very little work had been done on the osteology of the Siluroids. The only exhaustive paper on the subject is by James Kindred[10] on the skull of *Amiurus catus*. In the present paper I propose to describe the skull of the catfish—*Rita buchanani* (Ham. Buch.), which will serve as a type and further wish to extend the study to other species of siluroid fishes and deal with them from a comparative point of view.

The fishes have been collected fresh from the Calcutta markets. After identifying them the heads were dissected out and skulls prepared by removing the muscles, occasionally dipping them in hot water. Before removing the loose bones from the head great care was taken to note their position in relation to the neighbouring bones to avoid erroneous rearticulation. Here I desire to express my gratitude to Dr. B. K. Das, D.Sc. (Lond.), for his very valuable guidance throughout the course of this investigation. This work was commenced while I was a post-graduate student at the University College of Science, Calcutta, and the latter half of the work was carried out at the Zoological Laboratory of the Mysore University and I am indebted to Professor C. R. Narayan Rao for all the help given me for the completion of the paper. The drawings illustrating this paper have been made under my guidance by one of my old pupils Mr. T. R. Doreswami to whom my best thanks are due.

PART I. THE SKULL OF *RITA BUCHANANI* (Ham. Buch.)

I. *General Features of the Cranium.*

The cranium (Figs. 3, 4 and 5) is long and there is a gradual slope from behind forwards, *i.e.*, from the supraoccipital to the supraethmoid bone. Extending backwards from the cranium is an enormously developed supraoccipital process which is bifid posteriorly for the insertion of the basal bone of the dorsal fin. In the anterior region there is a corresponding, forwardly directed, bifid cornu of the supraethmoid. On either side are prominently seen the ectethmoid process, the outwardly extended ridge of the sphenotic and the upper limb of the post-temporal (Fig. 2). The upper surfaces of the supraoccipital, supratemporals, superior limb of the post-temporals and the posterior portions of the frontals are marked by granular ossifications, and in this part of the cranium there is only a thin covering of the skin, while the rest of the surface of the cranium is situated on a deeper level and is partly smooth and partly ridged and covered over by muscles and skin. The cranial roof is incomplete, there being an anterior fontanelle bounded mostly by the anterior portions of the frontals and partly by the posterior notch of the supraethmoid.

The parasphenoid axis is horizontal and straight, except for a slight downward extension of the basioccipital. Prominently seen on the ventral surface is a very large vomer with two broad oval plates with beadlike teeth (Fig. 3).

The cavum cranii extends widely up to the ethmoid region. Hence it is a platybasic cranium. There is a cartilaginous internasal septum.

(*a*) *Supraethmoid* (Figs. 2 and 7, SE.).—The anteriormost element of the cranium is the supraethmoid. This bone is bifurcated posteriorly, its notch forming the anterior boundary of the single dorsal fontanelle. There is a small depression in the middle line sloping from the centre backwards. The bone tapers anteriorly and at the end spreads out into two small horn-like processes. The dorsal surface of the bone is covered with fine ridges, which at the anterior end diverge on the two horns. Ventrally there is a short backward extension of this bone for the articulation with the parasphenoid. Both the dorsal and the ventral articular surfaces are highly split up into a number of osseous spicules, which serve for a firm interdigitation with the corresponding spicules of the frontals and the parasphenoid respectively. The supraethmoid articulates with the frontals and parasphenoid posteriorly, vomer and premaxillaries ventrally, and ectethmoids laterally.

(*b*) *Ectethmoids* (Figs. 2 and 7, ECT.).—The ectethmoids are situated on either side of the supraethmoid. Each ectethmoid has two small lateral processes situated side by side forming the anterior boundary of the orbit. Dorsally the posterior portion is elevated to the level of the frontal, and there is a small projection of the bone directed anteriorly. There are two nerve foramina, one above the other, for the passage of the two branches of ophthalmicus superficialis trigemini. Mesially the ectethmoid is produced into two lamina projecting dorsally and ventrally inwards, which form partly the roof, outer side wall and floor of the foramen orbito nasale. This portion of the bone remains incompletely ossified, whereas the lateral and dorsal portions are very well ossified. On the outer side there are two small articular surfaces, one situated dorsally and anteriorly to the other; the former is for the articulation of the lacrymal and the latter for the palatine (Fig. 7). Both these surfaces are only partially ossified.

Dorsally the ectethmoid articulates with the supraethmoid, and ventrally with the vomer. There is a firm interdigitation posteriorly and mesially with the frontals. There is only a small area of interdigitation with the orbitosphenoid and a very slight articulation with the ectopterygoid.

[In the ethmoid region the two ectethmoids do not meet each other in the middle line. At the base the ectethmoids are separated by a thin flat horizontal piece of cartilage, and correspondingly there is another sheet of cartilage on the upper side, forming the floor and the roof respectively of the olfactory passages. Between these two is a vertical sheet of cartilage, in the middle line, which does not, however, extend as far back as the orbitosphenoid. This is the internasal septum which separates the olfactory passages and partly the olfactory capsules (Fig. 6).]

(*c*) *Vomer* (Fig. 3, VO.).—This is a very large, conspicuous bone on the ventral portion of the ethmoid region. It is exceptionally large in *Rita*. It has a slender mesial portion tapering to a point backwards, which may be either entire or split up for articulation with the parasphenoid. Extending laterally are two large oval discs which are united to each other through the central portion in the anterior region. The two discs, however, diverge backwards. There is a short anterior process which extends only up to the premaxillaries. The whole of the ventral surface of the two discs is beset with rounded molariform teeth. The vomerine teeth are placed in sockets. On the dorsal surface there are two small depressions, one on each side, which serve as the floor of the nasal fossæ. The articulations on the dorsal surface are with the ectethmoids, supraethmoid and ectopterygoid. Posteriorly, as stated above, the central narrow portion fits into the parasphenoid.

(*d*) *Frontals* (Fig. 2, FR.).—These are two long dermal bones on the dorsal surface of the skull. The anterior half of the bone is thinner than the posterior half, and tapers to a point in front, and is split up into a number of spicules for the interdigitation with the supraethmoid and the ectethmoid bones. The anterior halves of the frontals are separated by the wide fontanelle. The portions of the frontals posterior to the fontanelle are united in the middle line by a suture, and form a compact roof of the cavum cranii in that region. At the hinder region, a short winglike lateral extension is given off from each frontal for articulation with the sphenotic. There is a small ventral ridge projecting downwards in the middle line which does not, however, extend to the anterior extremity of the bone. This ridge gives articulation to the ventrally disposed bones and also forms to a very slight extent, the side wall of the cranial cavity. On the dorsal surface the entire length of the narrow portion of the frontal is sculptured with ridges. Its hinder portion is wider and is covered over by granulations, which are in continuation with those of the supraoccipital. The supraorbital branch of the sensory canal from the sphenotic passes through the frontal and enters the tubular nasal bone in front.

Anteriorly the frontals are articulated by means of interdigitation with the supraethmoid and the ectethmoids, mesially with the posterior half of the frontal of the opposite side, and at the hinder end with the supraoccipital. On the ventral side it interdigitates by means of two small patches with the orbitosphenoid and the alisphenoid.

(*e*) *Orbitosphenoid* (Figs. 6, 7 and 8, OS.).—It is a large unpaired, boat-shaped bone with a thin flat horizontal base and two lateral, upwardly directed portions forming respectively the floor as well as the side-walls of the cranial cavity in this region. The side-wall is quite thick, and consists of two laminæ between which the cartilage is poorly ossified. Posteriorly there is a notch which forms nearly half the anterior boundary of the optic foramen, the rest of the boundary of this foramen is formed by front portions of the suprasphenoid and alisphenoid (Fig. 7). Ventrally the bone has a longitudinal groove which fits over the parasphenoid. Posteriorly it articulates with the suprasphenoid. The posterior halves of the lateral walls of the bone interdigitate with the frontals. Anteriorly it articulates by means of two patches of interdigitation, one on each side, with the ectethmoids. Externally and anteriorly there is an articular surface by means of which the ectopterygoid is attached to this bone (Fig. 7, ECP.).

(*f*) *Suprasphenoid* (Fig. 6, SS.).—This is a large unpaired bone fused completely on its ventral side with the posterior portion of the parasphenoid. It forms the floor of the cavum cranii between the optic and the trigeminal foramina. Anteriorly it interdigitates with the orbitosphenoid and also contributes slightly towards the formation of the boundary of the optic foramen and posteriorly with the prootics. There are two slightly raised portions on each side of this bone, by means of which it articulates with the alisphenoids.

(*g*) *Alisphenoids* (Fig. 7, ALIS.).—Alisphenoid is a considerably large, flat, wing-like bone situated between the optic and the trigeminal foramina. The posterior boundary of the former and the anterior boundary of the latter are largely contributed by this bone. The alisphenoids form the lateral walls of the cranium in this region. Its outer surface is fairly smooth, while its inner surface is ridged. On the posterior region of the outer surface of this bone there is a small depressed oval patch over which the anterior upper portion of the hyomandibular rests. There are no nerve foramina n this bone.

Anteriorly the alisphenoid meets the posteriorly directed process of the orbitosphenoid by the intervention of a small piece of cartilage. Dorsally it articulates with the frontal, and behind with the sphenotic by means of two patches of interdigitation. The upper posterior portion of the bone meets the prootic, completing the boundary of the trigeminal foramen. Ventrally towards its inner side it articulates with the suprasphenoid, and externally with the parasphenoid.

(*h*) *Parasphenoid* (Figs. 3 and 6, PS.).—The parasphenoid is a long bone forming the base of the cranium. It extends from the lower limb of the supraethmoid to the basioccipital. Both anteriorly and posteriorly the bone is split up into spicules. Posterior to the orbitosphenoid this bone extends dorsö-laterally, forming the characteristic wings of the Teleostean parasphenoid. It is over this portion of the bone that the suprasphenoid is anchylosed.

Anteriorly it articulates with the lower limb of the supraethmoid, and on the upper surface, from before backwards, with the orbitosphenoid, suprasphenoid (with which it is fused) and prootics which meet in the middle line over the parasphenoid. Laterally it articulates with the alisphenoids and partly also with the orbitosphenoid and the prootics.

(*i*) *Sphenotics* (Figs. 2 and 4, SPH.).—The dorsal surface of the sphenotic along with that of squamoso-pterotic forms a small well-defined lateral platform, situated on a level, slightly lower than that of the dorsal surfaces of the supraoccipital and the frontals. Viewed from above the sphenotic appears as a smooth flat bone, except for a thick anterior ridge which projects out into a broad spinous process. Behind this ridge is a small groove for the insertion of the opercular muscles and ligament.

The bone extends downwards into a thick ridge which forms lateral wall of the cranium above the trigeminal and facial foramina. Its lateral surface is fairly well grooved for the articulation of the hyomandibular. This articular facet is continuous with a similar groove on the squamoso-pterotic. Below this facet, however, the bone is considerably ridged. On the hinder side of the bone there is a small recess which is the anterior portion of the recess which lodges the anterior semicircular canal. The upper portion of the bone is pierced by the lateral line sense canal.

Internally and dorsally its articulation is with the frontal and the supraoccipital; anteriorly with the alisphenoid by means of two sutures; posteriorly with the squamoso-pterotic, and on the lower side it meets the prootic.

(*j*) *Prootics* (Figs. 3 and 4, PRO.).—These are two large flat bones situated immediately behind the trigeminal foramen and in front of the exoccipitals. The lower edges of the two bones meet in the middle line behind the suprasphenoid. They form the floor and more than half of the side walls of the cavum cranii in the otic region. The outer surface of each bone is smooth, except for the small ridges on its upper portion for the insertion of the hyomandibular muscles. In shape the bone is almost squarish, and its anterior portion is quite thin. It forms a portion of the boundary of the trigeminal foramen. Behind the latter there are two foramina, one large and another small, for the passage of the facialis nerve. Its inner surface is, however, not quite smooth. The lower portions of the prootics, as has been mentioned above, meet in the middle line, and they firmly press over the parasphenoid and the basioccipital. There is no trace of the 'eye-muscle canal' (myodome), which is present in other Teleosts.

There is a small depression, the pituitary fossa, between the suprasphenoid and the prootics, which lodges the hypophysis. There are two small recesses, one in each bone, at the base of the posterior surface. They are the anterior portions of the recessus sacculorum. About the middle region of the prootic there is a more or less prominent vertical ridge directed backwards, which gives rise to a corresponding groove. This groove lodges the greater part of the anterior semicircular canal (Fig. 6). There is another thin ridge at the posterior margin of the bone. Between these two ridges is a smooth, shallow depression with a thin wall, which lodges the recessus utriculi.

Anteriorly the prootics interdigitate with the suprasphenoid, and posteriorly with the basioccipital. The other neighbouring bones, except for a small patch of interdigitation with the squamoso-pterotic, are separated from the prootics by a thin strip of cartilage. On the dorsal side, each prootic meets the squamoso-pterotic, sphenotic and to a slight extent the alisphenoid also, and posteriorly the exoccipital.

(*k*) *Squamoso-Pterotics* (Figs. 4 and 5, SQPTR.).—There has been much confusion regarding the nomenclature of this bone. Hallman (in *Perca*, 1837) and Huxley (in *Esox*) called this bone squamosal ignoring its relation to the chondrocranium. But later Parker (1872), studying the development of *Salmo*, established its otic relationship, but yet its dermal character was not recognised. MacMurrich (1884) also named it only as pterotic. Sagemehl (1885, 1891) recognised both the elements in Cyprinidæ and Characinidæ, but still called it squamosal. Kindred (1919) who studied the development of skull in *Amiurus*, actually observed the dermal and the chondrocranial elements fusing to form a single bone, which he very rightly named as squamoso-pterotic. Exactly as in the case of *Amiurus* both the chondral and the dermal elements can be made out in the skull of *Rita.*

These two bones form the postero-lateral edges of the skull. The upper surface of each bone is smooth, except for a small elevated lateral area which is in level with the supratemporal and the epiotic limb of the post-temporal. The ventro-lateral surface is highly ridged for the insertion of the opercular muscles and ligament. There is an opening on the upper side of its lateral surface which opens into the post-temporal fossa. There is a groove present over the anterior upper portion of its side, and this forms a part of the articular facet for the hyomandibular bone. Viewed from inside there is a deep groove on the upper portion of the bone dividing it into two lamellæ, an upper representing the squamosal part and a lower the pterotic part. This groove is continuous with similar ones formed by the epiotic and the supraoccipital, and a more or less closed recess is formed by the apposition of the internal lamellæ of all the three bones. This does not open into the cranial cavity. It corresponds, more or less, to the pre-epiotic fossa of Ridewood (in *Clupea*). This cavity is in communication with the post-temporal fossa by an opening. The chamber in the lower pterotic portion of the bone forms the recess for the lateral semi-circular canal. This, again, is partly divided by a vertical bridge of bone, which serves as the anterior wall of the posterior semicircular canal. The squamosal part of the bone is pierced by the sensory canal which is described elsewhere.

The bone articulates anteriorly with the sphenotic, ventrally with the prootic and exoccipital by means of two sutures, posteriorly with the epiotic and supratemporal, and mesially with the supraoccipital.

(*l*) *Epiotics* (Figs. 3 and 4, EPO.).—They form the postero-dorsal angles of the skull. The bone is pyramidal in form with three sides, *viz.*, dorsal, posterior and lateral surfaces. The apex forms the postero-lateral corner. The dorsal surface forms the floor of a fossa which is roofed over by the supratemporal. Bridge and Haddon (1893) call this fossa in *Macrones* as " Post-temporal fossa ". The Post-temporal fossa of *Macrones* is deep and is formed by the fusion of the pre-epiotic recess and the shallow post-temporal fossa of *Rita.* This post-temporal fossa can be seen only when the post-temporal bone is detached from the cranium, because the epiotic limb of the latter fits into this fossa (Fig. 5, UF.). Laterally the bone is ridged for the insertion of the opercular muscles. Internally the cavity in the bone is divided into two by a transverse septum—the upper chamber forming a portion of the pre-epiotic recess, and the lower portion forms the recess for the posterior semicircular canal.

The articulations are with the supraoccipital and posttemporal above, exoccipital below, and squamoso-pterotic in front. There is considerable amount of cartilage between the exoccipital and the epiotic.

(*m*) *Supraoccipital* (Figs. 4 and 6, SO.).—The supraoccipital bone is exceptionally large, and forms the roof of the cranial cavity behind the frontals. Parietals are absent. Extending behind the occipital region the supraoccipital bears a very broad backwardly directed supraoccipital process. It is slightly more than half the total length of the bone. The supraoccipital process is bifurcated posteriorly for the reception of the basal bone of the dorsal spine. The dorsal surface is highly granulated, and is fairly convex. There are two small depressions on the anterior half of the bone, the nature of which is not known. Ventrally the anterior portion of the bone forms the roof of the cranial cavity, and posterior to this is a thick transverse downward portion of the bone which articulates with the exoccipitals. It forms the posterior wall of the cranium above the foramen magnum. The supraoccipital, however, does not contribute to the formation of the foramen magnum. In the middle of the posterior face of the cranium there is a small mass of cartilage between the supraoccipital and the exoccipitals. It is through the intermediation of this region that the spinous process of the fourth vertebra articulates with the cranium. On the mid-ventral surface of the occipital process is a thick vertical ridge of bone which extends backwards from the upper portion of the posterior surface up to the base of the basal bone. Laterally the bone is ridged for the attachment of muscles. Antero-laterally and also above the sphenotic and the squamoso-pterotic the bone gives attachment to the opercular and the mandibular muscles.

The supraoccipital articulates in front with the frontals, laterally with the sphenotic, squamosopterotic and supratemporal, and posteriorly and below with the epiotic and exoccipital. It is simply apposed with the exoccipitals, cartilage persisting between them.

(*n*) *Exoccipitals* (Figs. 3, 4, 5 and 6, EX.).—The exoccipitals are situated laterally on the two sides of the foramen magnum forming its complete boundary. The two exoccipitals meet each other in the middle line above the foramen magnum excluding the supraoccipital from its boundary. On the lower side, the exoccipital sends inwards a thin horizontal lamina of bone which meets in the middle with its fellow of the other side, forming the floor of the foramen magnum and also the roof of the sinus imparis. Posteriorly the bone is pushed inwards vertically giving rise to an internal ridge which, in continuation with a small portion of a ridge in the supraoccipital, forms the posterior boundary of the otic recess. And correspondingly there is a wide groove on the posterior surface which diverges upwards.

The lateral surface is squarish, and there is a minute foramen in the lower anterior portion for the passage of the glossopharyngeal nerve. Posterior to this lies the wider aperture for the exit of the vagus nerve (Fig. 4). There is another foramen at the posterior corner of the lateral surface of this bone for the hypoglossal or the first spinal nerve. On the ventral surface of the bone is a deep, smooth groove, closed behind, which forms the outer sidewall and the roof of the recessus sacculi. Directed ventro-laterally is a small process which with a similar bigger process of the basioccipital forms the articular facet for the inferior limb of the post-temporal of that side.

The articulations of this bone are with supraoccipital, epiotic and squamoso-pterotic above; prootic in front; basioccipital below and with its fellow of the other side mesially. Except for a little junction with the epiotic, and also with the squamoso-pterotic and the basioccipital, its sides are simply apposed together with the neighbouring bones, cartilage still persisting between them.

(*o*) *Basioccipital* (Figs. 3, 4, 5 and 6, BO.).—The basioccipital is situated below the exoccipitals forming the posterior-most element on the ventral surface of the cranium. It is quite massive in the posterior region, becoming thinner anteriorly. The posterior surface is oval and concave with two ventro-posteriorly directed branched accessory processes for the articulation with similar processes growing forward from the first as well as the complex vertebra. The first vertebra is partly fused on its ventral side with these processes. Anterior to this the bone sends out two short but stout lateral processes, one on each side, which give attachment to the lower limb of the post-temporal. Between these two processes, on the ventral surface of the bone, is a small circular, hollow space filled with cartilage. The ventral surface is smooth. The anterior portion is highly split up for interdigitation with the parasphenoid and the suprasphenoid.

On the upper surface of the bone is a longitudinal vertical ridge in the middle line on either side of which is a wide groove closed posteriorly, forming the floor of the recessus sacculi, while its inner sidewall is formed by the ridge itself. The ridge is wide and concave upwards forming the floor and partly the sidewalls of the sinus imparis. The transverse groove for the ductus endolymphaticus in the anterior region of this bone is not quite distinct.

The articulations are with the parasphenoid and suprasphenoid in front, dorso-laterally with the prootics, dorsally with the exoccipitals, and laterally with the post-temporal.

(*p*) *Supratemporals* (Figs. 2, 4 and 5, ST.).—There is a small, flat bone on either side at the postero-lateral dorsal surface of the cranium, roofing the post-temporal fossa. It is firmly articulated with the cranium. So far it has not been described in any of the siluroids by the previous workers. They can be clearly seen in *Macrones*, but Bridge and Haddon who have studied the posterior region of the skull have failed to record its presence. From its relative position on the skull and its relation with the lateral line sense canal it could easily be identified as supratemporal. The dorsal surface of the bone is covered over with granulations, and is in the same level as the supraoccipital and the upper limb of the post-temporal.

Articulations are with the supraoccipital towards its inner side, squamoso-pterotic in front, and post-temporal below.

(*q*) *Post-temporals* (Figs. 2 and 9, PT.).—The post-temporal is a bone which primarily belongs to the pectoral girdle. It has two limbs, *viz*., a large upper flat thumb-shaped portion and a ventrally directed rod-like portion. The inferior limb is smooth and articulates by its end on to the articular facet presented by the basi- and exoccipitals (Fig. 5, ART. PT.). The anterior portion of the upper limb is inserted into the post-temporal fossa. The dorsal surface of the upper flat portion is granulated. Between the two limbs there is a wide groove on the bone directed backwards with which articulates the clavicle. The sensory canal enters the cranium through the upper limb of the post-temporal.

The lower limb, as stated above, articulates with the basi- and exoccipitals, and the anterior portion of the upper limb with the supratemporal above and the epiotic below.

II. *Temporal and Preopercular Series.*

The post-temporals and the supratemporals have already been described.

(*a*) *Subtemporals* (Fig. 1, SBT.).—The outermost branch of the sensory canal in the squamoso-pterotic passes downwards posterior to the hyomandibular as the preopercular mandibular canal. Before it enters the preopercular the canal passes through two small tubular bones, on either side, known as the subtemporals.

(*b*) *Pre-operculum* (Figs. 1 and 8, PREO.).—From the subtemporal the sensory canal passes down the preoperculum and finally enters the mandible. The preoperculum has been treated with temporal bones because it is developed primarily around a portion of the lateral line system and is of a different nature from other opercular bones (Ridewood). The preoperculum is firmly articulated in front with the hyomandibular and quadrate. The lower portion of the bone is broad. There is a foramen in the lower part of the bone for the passage of a branch of the hyomandibularis facialis.

III. *Circumorbital Series.*

(*a*) *Infraorbital bones* (Fig. 7, IOR. 1-6).—Extending from the post-orbital process of the frontal there is a chain of small thin tubular bones, running below and in front of the orbit up to the lacrymal. They are superficially imbedded in the facial muscles. They are six in number, and the first three belong to the descending series, while the others to the ascending series, and are traversed by the suborbital portion of the lateral line canal.

(*b*) *Lacrymal* (Fig. 7, LA.).—Lying in front of the last infraorbital and belonging to the same series is the lacrymal bone. On its inner side it articulates with the facet presented by the ectethmoid on its anterolateral surface. The lacrymal has a long posteriorly directed spine-like process and a broad inwardly directed plate. The sensory canal traverses the posterior margin of the broad portion and opens to the exterior anteriorly.

(*c*) *Nasals* (Fig. 7, N.)—These are two small tubular bones lying in front of the frontals and on either side of the supraethmoid. They are not directly articulated to the cranium, but are imbedded in connective tissue. The supraorbital portion of the sensory canal emerges out of the anterior portion of the frontal and then passing through the nasal opens to the exterior in front.

IV. *Maxillary Series.*

(*a*) *Premaxillaries* (Figs. 1 and 8, PMX.).—They are attached firmly to the ventral surface of the anterior cornu of the supraethmoid. Each is more or less a rectangular bone, bearing on its ventral face seven to eight rows of pointed teeth. The two bones meet each other in the middle line. Dorsolaterally it is attached by ligament to the maxillary and the palatine.

(*b*) *Maxillaries* (Figs. 1 and 8, MX.).—The maxillary, as is well known, is a very much reduced bone in the Siluroids. It is edentulous and lies at right angles to the long axis of the skull. It is slightly thicker at the base having two knob-like processes and pointed at the tip. Its main function is to support the maxillary barbel. The cartilage of the barbel is lodged in the groove present on the posterior surface of the bone. It is attached to the premaxillary by means of ligament, and it also articulates with the palatine by the two knobs at its base. It is capable of considerable movement: when the palatine is pushed forward the pointed end of the maxillary is directed backwards, and whilst the former is withdrawn, the latter is pushed forward.

V. *Palatoquadrate and Hyomandibular Series.*

(*a*) *Palatines* (Figs. 1 and 8, PAL.).—The palatine is a long rod-like bone articulated on to the lateral surface of the ectethmoid, and lying parallel to the long axis of the skull. It has undergone considerable modification from the normal structure. It has lost its attachment with the pterygoquadrate bar. It is thin in the middle and is thicker at its two ends. Cartilage is present at the two tips. On the inner side of the posterior half of the bone is an articular facet for articulation with ectethmoid. The anterior end articulates with the maxillary and also is connected with the premaxillaries by ligament.

(*b*) *Ectopterygoids* (Figs. 1, 7 and 8, ECP.).—It is a small bone firmly attached to the lateral surface of the orbitosphenoid and also partly spreading over the vomer. It simply touches a portion of ectethmoid. Though it articulates with the anterior end of the metapterygoid it has lost its firm connection with the pterygoquadrate bar. When the pterygoquadrate bar is detached from the cranium the ectopterygoid actually remains attached to the orbitosphenoid and the vomer.

(*c*) *Metapterygoids* (Figs. 1 and 8, MPT.).—The anterior thick end of the metapterygoid articulates in front with the small ectopterygoid and to a slight extent with the orbitosphenoid. The bone becomes broader in the middle and again tapers backwards. On the upper side there is a longitudinal notch in which the bone is ridged. The posterior side is highly split up for interdigitation with the anterior limb of the quadrate. There is no direct connection of the metapterygoid with the hyomandibular.

(*d*) *Quadrate* (Figs. 1 and 8, Q.).—On the lower side of the hyomandibular and in front of the preopercular is the more or less triangular quadrate. The postero-ventral portion of this bone is thick and presents the grooved articular surface for the mandible. In front it interdigitates with the metapterygoid, above with the hyomandibular, and posteriorly with the preoperculum. In between the preopercular and hyomandibular articulation there is a small rectangular area filled with cartilage. This unossified piece of cartilage represents the symplectic.

(*e*) *Hyomandibular* (Figs. 1 and 8, HM.).—The hyomandibular is a huge, flat bone which connects the pterygoquadrate bar with the cranium. The upper side is arched and fits into the articular facet (already described) on the cranium presented by the sphenotic and the squamosopterotic. Projecting antero-dorsally is a small process which articulates on a smooth, shallow depression on the alisphenoid. Near the anterior margin is a foramen for the passage of the ramus hyomandibularis facialis. There is a knob on its posterior side for the articulation of the operculum. The bone is covered with a few ridges both on the inner and outer surfaces for the insertion of adductor muscles. Ventrally it articulates with the operculum and the preoperculum.

VI. *Mandibular Series.*

The mandible consists of two limbs, each of which is formed of the dentary and the articular bones.

(*a*) *Dentary* (Figs. 1 and 8, D.).—It is a curved bone slightly tapering anteriorly and united by ligament with its fellow of the opposite side at the symphysis. The upper surface is broad and is covered completely with teeth. A few rows of teeth at the anterior margin are rather small and pointed, and from there backwards they gradually increase in size and assume beaded nature. On the anteroventral surface is a series of six sensory canal openings. On the posterior portion of the inner surface is a groove which lodges the Meckel's cartilage. There are also a few nerve foramina on the inner surface of this bone for the passage of the small twigs of the mandibular branch of the 5th nerve. Posteriorly there is a small dorsal ridge at the place where it interdigitates with the articular.

(*b*) *Articular* (Figs. 1 and 8, ART.).—The articular is a massive bone possessing posteriorly the articular facet for the quadrate. On its inner surface is the posterior portion of the Meckel's cartilage. The angular is fused on with the articular. There is a portion of the lateral line canal passing through the ventral region of the bone. It articulates in front with the dentary and posteriorly with the quadrate.

VII. *Opercular Series.*

(*a*) *Operculum* (Fig. 1, OP.).—It is more or less, a flat, triangular bone with a concave articular surface for articulation with the knob on the hyomandibular. The outer surface is sculptured. The lower apical end is connected with the interoperculum by means of ligament.

(*b*) *Interoperculum* (Fig. 1, IOP.).—This is a small bone which is attached by means of ligament dorsally with the apex of the operculum, on the inner side with the upper portion of the epihyal, and anteriorly with the mandible. The suboperculum is absent in *Rita*.

VIII. *Lateral Line System.*

The lateral line sense canal on either side of the body divides into two branches before entering the skull. The post-temporal receives these branches by two independent openings and passing through the bone, the outer branch enters the squamoso-pterotic directly while the inner passes through the supratemporal before entering the squamoso-pterotic. The two branches unite together in the squamoso-pterotic and sends out a lateral branch which passes downwards through the subtemporals, preopercular, articular and the dentary, forming the preopercular mandibular branch. Then the main canal passes forwards and enters the sphenotic. At the anterior end of the sphenotic it divides again forming the outer—infraorbital branch—which passes through the thin, tubular infraorbitals and the lacrymal; and the inner—supraorbital branch—which passes through the frontal and the nasal. Finally, the two branches open to the outside in the region of the snout.

SUMMARY.

The skull of *Rita buchanani* is comparatively massive indicating inefficient ossification. Cartilage still persists considerably in all the parts of the cranium, hyomandibular and palatine and as Meckel's cartilage. Except for small patches of interdigitation, the cartilage bones in the cranium are separated by tracts of intervening cartilage. Besides, the bones themselves are not very well ossified except for the inner and outer surfaces.

The cranium is platybasic, the cranial cavity extending widely between the orbits to the ethmoid region. There is the median supraethmoid and the two lateral ectethmoids. The two nasal fossæ are partly separated by a thin cartilaginous internasal septum. On the ventral side of this region is the single, large, bilobed, toothed vomer. Posterior to this is the sphenoid region with the single boat-shaped orbitosphenoid, the two winglike alisphenoids, the suprasphenoid and the parasphenoid. The floor of the cranial cavity in this region is formed by the basal portion of the orbitosphenoid and the suprasphenoid. The lateral walls are constituted by the upward extensions of the orbitosphenoid and the alisphenoids. The suprasphenoid is firmly fused with the dorsal surface of the posterior half of the long parasphenoid. There is no interorbital septum. The cranial cavity in the auditory region is wide and there are all the otic bones except the opisthotics. The floor of the cranial cavity in this region is formed by the inward extensions of the ventral portions of the prootics which meet each other in the middle line. The prootics are firmly attached to the parasphenoid and basioccipital. Hence the myodome is completely absent. Lastly, there is the occipital region which forms the posterior wall of the cranium. The basioccipital has a large oval articular surface for the vertebral column and two short processes laterally one on each side for the inferior limb of the post-temporal. On the two sides of the foramen magnum are the exoccipitals. The upper portion of the posterior wall is formed by the supraoccipital. There is a strong supraoccipital process. On either side of the postero-lateral angles of the cranium is the small supratemporal forming the roof of the post-temporal fossa into which the epiotic limb of the post-temporal fits. Communicating with the post-temporal fossa by a wide foramen and situated in front of it, is the pre-epiotic recess.

The posterior region of the cranium is roofed by the supraoccipital. The parietals are absent. In front of the supraoccipital are the two frontals. There is a fontanelle between the anterior portions of the frontals, behind the supraethmoid.

The post-temporal is firmly articulated with the cranium. The bifid anteriorly directed spinous process of the fourth vertebra articulates with the supraoccipital and the exoccipitals above the foramen magnum.

Connected with the lateral line canal are the small tubular bones, infraorbitals, lacrymals, nasals and subtemporals. The preoperculum also belongs to this series.

There are two pterygoid bones, the ecto- and the metapterygoid. The ectopterygoid and the palatine have lost their firm connection with the pterygoquadrate bar, being connected with it only by connective tissue. The latter is modified into a rod-like bone.

The maxillary is very much reduced in size, edentulous and acts as a support for the maxillary barbel. The premaxillaries are small flat bones with sharp teeth.

In the opercular series the suboperculum is wanting.

There are only two elements in the lower jaw—the dentary and the articular; the angular is fused with the latter.

PART II. SHORT DESCRIPTIONS OF THE CRANIOLOGY OF CERTAIN OTHER SILUROID FISHES AND THEIR PHYLOGENETIC RELATIONSHIPS.

A. THE SKULL OF *Silundia gangetica*.

The cranium of *Silundia* (Fig. 10) is broad and convex on the dorsal surface. A posteriorly directed portion of the ectethmoid meets the sphenotic outside the frontal. There is a gradual slope from the supraoccipital to the supraethmoid bone. There are three fontanelles in the roof of the cranium.

The supraoccipital spine is prominent but it does not, however, extend backwards of the occipital region. Continued ventrally from the spine is the supraoccipital ridge. The two antorbital processes of the ectethmoids are prominently seen in the anterior region.

Ventrally the parasphenoid axis is straight. There is a T-shaped toothed vomer. The cranial cavity in front of the auditory region is narrow. The alisphenoid, downward extension of the frontal and the lateral wall of the orbitosphenoid of one side are closely apposed with the corresponding fellows of the other side leaving only a narrow space through which the olfactory nerves pass forwards. In front of the auditory region and on the outer sides of alisphenoids are two wide shallow cavities each bounded by the alisphenoid, frontal and the sphenotic. In front of the orbitosphenoid there is a vertical cartilaginous septum. The olfactory capsules are wide apart.

The ridge on the dorsal surface of the supraoccipital spine is continuous anteriorly with a crescentic ridge over the posterior portions of the frontal and the sphenotic. Posterior to this ridge the cranium slopes backwards. On either side of the supraoccipital, there is an arcade formed by the meeting of a small rodlike postero-lateral process of the supraoccipital with a similar process of the epiotic directed anteriorly inwards. There is another thin splint-like process of the supraoccipital. The supraoccipital does not contribute to the formation of the foramen magnum. Posteriorly the nerve openings in the exoccipitals, on either side of the foramen magnum, are very wide.

The post-temporals are not strong and are not articulated firmly with the cranium. Each has the usual epiotic and basioccipital limbs. There is no regular articular process on the basioccipital for the lower limb of the post-temporal. In front of the epiotic limb of the post-temporal is a scale-like supratemporal which is articulated with the epiotic and the squamoso-pterotic.

The orbitosphenoid is fairly big and the two upwardly directed lamellæ fuse with each other in the upper region of the anterior portion leaving an olfactory passage. The suprasphenoid is fused with the parasphenoid. The remarkable feature about the primitive skull of Silundia is the presence of the vestige of the myodome. The prootics do not articulate with each other in the middle line throughout their length, but only the posterior halves of the bones send inward processes which meet each other. These are not firmly pressed over the parasphenoid and the basioccipital but leave a small space which is closed behind. This small recess floored by the parasphenoid and roofed by the prootics, though very small corresponds morphologically to the eye-muscle-canal.

The bones are highly vacuolated and spongy. Cartilage persists to a very great extent in all the parts of the cranium. Masses of unossified cartilage can be seen between the inner and the outer lamellæ of the cartilage bones.

The infraorbitals and the nasals are thin, tubular bones.

The pterygoquadrate bar is articulated with the cranium posteriorly through the hyomandibular and anteriorly by the ento- and ectopterygoids. The entopterygoid is a very small bone. The ectopterygoid is toothed and the teeth are in continuation with those of the vomer. Thus there are all the three pterygoid bones—ento-, ecto- and metapterygoids. The symplectic cartilage is present The palatine, unlike in other forms, is scale like. It articulates on its inner side over the ectethmoid and anteriorly with the maxillary.

The premaxillaries are attached to the ventral surface of the supraethmoid. The maxillaries are small, edentulous and support the maxillary barbels.

The suboperculum is absent.

The mandible consists of the dentary and the articular.

B. THE SKULL OF *Plotosus canius*.

The upper surface of the cranium is flat and slopes gradually from behind forwards (Fig. 11). The ethmoid region tapers anteriorly from the antorbital processes of the ectethmoids ending in the supraethmoid cornu. The ectethmoid does not meet the sphenotic. There are two fontanelles on the upper surface of the cranium. In the middle of the supraoccipital is a small foramen leading into the cranial cavity. The supraoccipital process is small.

Ventrally there is a broad triangular vomer with a posteriorly directed articular process. It is covered with molariform teeth imbedded in sockets. The foramen magnum is very wide and is bounded entirely by the exoccipitals. The complex vertebra articulates with cranium both by the centrum and also by the spinous process of the fourth vertebra. The posttemporal is weak. There are two supratemporals on either side, one of which is a small ossicle. The subtemporal foramen on the lateral surface of the squamoso-pterotic opens into the cranial cavity.

Internally the cranial cavity extends widely to the anterior region. Only the posterior halves of the prootics meet each other in the middle line, and are firmly pressed over the parasphenoid and the basioccipital. Hence the eye-muscle canal is completely absent. A small area of the parasphenoid between the prootics and the suprasphenoid forms the floor of the cavum cranii. The suprasphenoid is fused with the parasphenoid. In front of the orbitosphenoid is a cartilaginous internasal septum.

The infraorbitals are very thin and tubular bones.

There are wide tracts of cartilage between the cartilage-bones and the bones themselves are not well ossified.

The pterygoquadrate bar articulates with the cranium through the hyomandibular posteriorly and by the ectopterygoid anteriorly. At the anterior end of the articular surface of the hyomandibular is an anterior process which fits into a groove in the alisphenoid. The symplectic cartilage is broad. The quadrate is not directly articulated with the hyomandibular but only through the preopercular, symplectic cartilage and the metapterygoid. The palatine is comparatively big. It is rod-like anteriorly and broad posteriorly.

The premaxillaries are broad. The maxillaries are fairly big and the groove for the insertion of the cartilage of the barbels is not well developed.

The mandible is strong. The dentary is covered with molariform teeth. Angular is fused with the articular.

There is an operculum, an inter-operculum and a small, rudimentary suboperculum.

C. THE SKULL OF *Wallago attu*.

The cranium (Fig. 12) is deeply situated and is rather flat sloping slightly forwards and backwards from the middle of the supraoccipital. There is a small supraoccipital crest. There are two narrow fontanelles on the upper surface of the cranium. The posteriorly directed limb of the ectethmoid meets the anterior portion of the sphenotic outside the frontal. The lateral line canal is not deeply situated; the sphenotic and the frontal portions run partly in the grooves on the upper surface of the bones. The antorbital processes of the ectethmoids are prominent.

The parasphenoid axis is straight. The vomer is T-shaped with two postero-laterally directed small patches of sharp teeth. There are two shallow wide fossæ in front of the auditory region as in *Silundia*. The cranial cavity is spacious in the auditory region and is narrow in front. The lower ends of the prootics meet in the middle line and are firmly pressed over the parasphenoid and basioccipital. The orbitosphenoid is big and in front of it is a cartilaginous septum in continuation of which bony septum is developed by the supraethmoid.

There is no well-defined posterior surface of the cranium since there is a gradual slope from the supraoccipital backwards. The foramen magnum is triangular and is formed by the exoccipitals. The post-temporal is loosely attached to the cranium. The inferior limb of the post-temporal is weak and is inserted into a depression on the lateral side of the basioccipital.

The infraorbitals are four in number, the first and the third are fairly long, of which the latter articulates on the ectethmoid. There is a small lacrymal and a thin, tubular nasal bone on each side.

Externally the cranium appears to be well ossified. But when the bones are detached and examined, persisting cartilage could be seen in all the cartilage bones.

The pterygoquadrate bar consists of a small ectopterygoid, metapterygoid and quadrate. The articular facet on the cranium for the hyomandibular is almost formed by the sphenotic. The symplectic cartilage is small and narrow. The palatine is a very small bone.

Comparatively the maxillary is long with two knobs at the base and a groove on its inner face. The premaxillary is exceptionally large measuring slightly more than half the length of the cranium and bears rows of sharp curved teeth. Hence the fish has a very wide mouth.

The dentaries are also long with sharp teeth. The angular is fused with the articular. The suboperculum is absent.

D. THE SKULL OF *Pangasius buchanani*.

The cranium (Fig. 13) exhibits three prominent lateral processes on each side formed by the supraethmoid, ectethmoids and the upper limb of the post-temporals and a long supraoccipital process behind. All the bones are sculptured. Postero-laterally there is a cranial foramen which opens into the pre-epiotic recess.

On the ventral surface is a small T-shaped, toothed vomer with a short anterior process. The basioccipital is massive and broad. Laterally the foramen for the passage of the fifth and the seventh nerves is wide and is almost entirely bounded by the alisphenoid. The squamoso-pterotic does not contribute to the articular facet for the hyomandibular. It is formed by the lateral surface of the sphenotic and partly by the alisphenoid. On the upper portion of the orbitosphenoid and in front of it are two wide openings communicating the cranial cavity in this region with the exterior.

Posteriorly the long supraoccipital process is very conspicuous and measures slightly more than half the length of the cranium. The first centrum is firmly articulated with the basioccipital. The complex vertebra articulates firmly with the split postero-ventrally directed processes of the basioccipital and also by the spinous process of the fourth vertebra with the supraoccipital ridge and the exoccipitals. The post-temporals are thick and are firmly attached to the cranium.

The cranial cavity extends widely to the ethmoid region. There is no eye-muscle canal. In front of the orbitosphenoid is a vertical cartilaginous septum.

There are strips of cartilage separating the cartilage bones. The bones are fairly well ossified.

The infraorbitals are small, thin bones. There is a small subtemporal above the preoperculum.

The pterygoquadrate bar is composed of a small ectopterygoid, metapterygoid and the quadrate. The palatine has the usual rod-like shape.

The premaxillaries and the maxillaries have the normal structure.

The mandible consists of the dentary and the articular.

The suboperculum is absent.

E. THE SKULL OF *Macrones aor.*

The cranium (Fig. 14) is long and is compressed dorso-ventrally in the anterior region. The dorsal surface is more or less uniformly wide throughout. The supraoccipital process is long and narrow. There are two fontanelles on the upper surface of the cranium. The ectethmoid does not meet the sphenotic. On the ventral surface is a broad toothed vomer.

On either side of the postero-lateral corner of the cranium is a deep fossa open posteriorly, floored by the inner ridges of the squamoso-pterotic, supraoccipital and the upper surface of the epiotic and roofed by the squamosopterotic, supraoccipital and the supratemporal bones. This fossa is termed post-temporal fossa in Macrones by Bridge and Haddon. The epiotic limb of the post-temporal fits into this fossa. The post-temporal is excavated on the posterior face for reception of the anterior end of the air-bladder.

The bassioccipital has two postero-mesially directed accessory articular processes. The complex vertebra articulates secondarily with these processes and also by the spinous process of the fourth vertebra on the supraoccipital and the exoccipitals above the foramen magnum.

There is no trace of the myodome. The orbitosphenoid is long. There is a thick horizontal piece of cartilage between the two ectethmoids. The nasal fossæ are wide apart.

There are small strips of cartilage separating the cartilage bones. The bones are well ossified.

The infraorbitals and the nasals are thin, small bones.

The pterygoquadrate bar consists of a very small, curved ectopterygoid, metapterygoid and the quadrate. The symplectic cartilage is present. The palatine is a thin rod-like bone. The premaxillaries are covered with fine sharp teeth. The maxillaries are long with the groove on their inner surface.

The opercular and the mandibular elements are normal.

F. THE SKULLS OF *Arius sona* AND *Arius sagore*.

The cranium of *Arius sagore* (Fig. 15) is broad and compressed, and there is a single fontanalle above the orbitosphenoid while the cranium of *A. sona* (Fig. 16) is long and has two, an anterior large and a posterior small, fontanelles. All the bones on the upper surface are compactly articulated in *A. sagore* but in *A. sona* there are two pairs of small open spaces, one in the anterior region bounded by the ectethmoid and the frontal, and the other in the postero-lateral corner between the post-temporal, squamoso-pterotic and the supratemporal. The upper surfaces of the roofing bones are granulated. The supraethmoid is broad. There is a broad supraoccipital process. Portion of the epiotic has become superficial on the dorsal surface and is granulated.

The parasphenoid axis is concave and the parasphenoid is broad anteriorly. It has two antero-laterally directed thin pointed processes one on each side, in front of the optic foramen, over which the optic nerve passes to the eye. The vomer is small and has two oval patches of sharp teeth. In another *Arius* sp. the vomer is very small and edentulous and there are two very prominent ectethmoid knobs. The auditory recesses are spacious and consequently the auditory bones are pushed out on the sides to form prominent rounded bullæ in the postero-lateral region of the cranium. The ear-ossicles are big.

The remarkable feature about the posterior region of the skull of *Arius* is the firm articulation of the complex vertebra with the cranium. The complex vertebra is long and is formed by the fusion of 7 to 8 vertebræ. The two postero-ventrally directed articular processes of the basioccipital, which have been described in other crania, have fused together enclosing a small circular canal for the passage of the hæmal artery. This broad split surface of the basioccipital articulates intimately with a similar surface of the complex centrum and forms a ventrally directed sub-vertebral process. There is a rigid articulation of the spinous process of the fourth vertebra with the supraoccipital and the exoccipitals above the foramen magnum. Besides, there are two lamellar portions of the epiotics directed postero-inwards which firmly interdigitate with similar antero-laterally directed transverse processes of the fourth vertebra. Bridge and Haddon[4] have stated that the postero-inwardly directed ridges are processes of the supraoccipital. This is clearly an erroneous observation. Though the processes pass immediately by the side of the supraoccipital they are actually lamellæ of the epiotics. The post-temporal fossæ are absent and the supratemporals are comparatively broad. The post-temporal is firmly articulated with the cranium. In *A. sagore* there are a few small bony ossicles posterior to the post-temporal enclosing portion of the lateral line canal.

There is no trace of the myodome. The suprasphenoid is fused with the parasphenoid. The cranial cavity stops short about the middle of the orbitosphenoid. The two olfactory nerves pierce through independent openings in the anterior portion of the orbitosphenoid which continue into the ectethmoids. The olfactory capsules are wide apart. There is a thick, horizontal sheet of cartilage between the two ectethmoids.

All the bones are well ossified.

In *A. sagore* the infraorbitals are thin and tubular but in *A. sona* they are thick and sculptured on the outer surface.

The hyomandibular possesses a thick anterior process. There is a long strip of symplectic cartilage. The metapterygoid is broad. The ectopterygoid is covered with sharp teeth and is articulated on the ventral surface of the ectethmoid. The metapterygoid is connected with the ectopterygoid only by connective tissue. The palatine is comparatively very small and rod-like.

The maxillaries, the mandibles and the opercular apparatus are normal.

G. THE SKULL OF *Osteogeneosus militaris*.

The anterior and posterior regions of the cranium (Fig. 17) are broad while it is narrow in the middle. There is a wide fontanelle over the orbitosphenoid, posterior to which is another smaller one. There is an arcade on either side in the anterior region formed by the junction of the antero-laterally directed limb of the frontal with a postero-laterally directed portion of the ectethmoid. The lateral upper surface of the ectethmoid is broad and is covered with honey-combed structure probably for the lodging of some glandular body. The supraoccipital process is prominent. The bones are covered with granules and some are also sculptured.

The parasphenoid axis is concave. There is a very small edentulous vomer. The optic foramen is small, pushed backwards and is almost completely bounded by the suprasphenoid. The auditory bullæ are prominent.

In the posterior region, the firm articulation of the complex vertebra with the cranium is almost exactly similar to the condition found in *Arius*. The post-temporals and the supratemporals are rigidly attached to the cranium. There are no post-temporal fossæ.

The cranial cavity does not extend in front of the orbitosphenoid. There are two very small foramina in the anterior portion of the orbitosphenoid for the passage of the olfactory nerves. The nasal capsules are formed by the supraethmoid.

The bones are well ossified.

The infraorbitals and the nasals are small and tubular. The ectopterygoid is broad and is covered with molariform teeth. It is articulated on the ventral surface of the ectethmoid and the orbitosphenoid and by means of connective tissue with the metapterygoid. The palatine is thick and has a broad articular surface on its inner side.

The mandible is normal.

The opercular apparatus consists of the operculum, interoperculum and a small, vestigeal suboperculum.

DISCUSSION AND SUMMARY.

Among the eight forms of siluroid fishes that have been described there is a progressive growth both in the ossification and the specialisation of the skull, more or less, in the following order: *Silundia*, *Plotosus*, *Wallago*, *Rita*, *Pangasius*, *Macrones*, *Arius* and *Osteogeneosus*. A survey of the osteological features of these forms reveals that the Siluridæ exhibits certain primitive characters indicating its origin from the primordial Teleostean fishes. But the advanced forms like the *Arius* and *Osteogeneosus*, however, possess very highly specialised features which have developed in the family through the long age it has survived. The group had attained a high degree of specialisation even as far back as the Eocene times since a species of *Arius*—*Arius egertoni*—has been described from the Barton clay (Upper Eocene) of Hampshire.

The platybasic nature of the siluroid cranium, as in ganoid fishes, is a primitive character. While the cranial cavity passes over the orbitosphenoid to the ethmoid region in all the forms it stops short above the middle of the orbitosphenoid in *Arius* and *Osteogeneosus* and only the olfactory nerves pierce separately through the orbitosphenoid and ectethmoids. In *Arius* and *Osteogeneosus* the cranium cannot strictly be regarded as platybasic and the anterior half of the orbitosphenoid forms to some extent the interorbital septum.

The presence of a well-developed orbitosphenoid is also an archaic feature. But its persistence even in the highly specialised forms is probably due to its position to strengthen the attachment of the ethmoid region with the rest of the cranium. Gregory[21] explains this point thus: "In the midst of these and other specialisations the orbitosphenoid element is strongly developed, perhaps because it is needed to stiffen the immense skull and the nuchal spine." Tate Regan[19] states that the suprasphenoid (basisphenoid) is absent. But this element is fused with the parasphenoid and can be made out in all the forms under consideration. The vomer is large and toothed in the primitive forms, whereas it is very small and edentulous in the advanced *Osteogeneosus* and a species of *Arius*.

The possession of superficial covering bones is regarded as a primitive character.[6] But the superficial nature of the bones in the skulls of the advanced Siluroids is only a secondarily acquired feature. This can clearly be made out by the fact that the skull is deeply situated in the primitive genera (*Silundia, Wallago* and *Plotosus*) whereas it becomes gradually superficial among the higher forms (*Rita*, *Pangasius*, *Arius* and *Osteogeneosus*) in which the bones are covered with denticles and are compactly articulated, forming strong protective shield in some forms. Goodrich[6] points out: "It is, of course, possible that the denticles on the surface of the body of the *Siluridæ* have been, so to speak, reacquired; the bony plates on which they rest seem to be secondary, since they often overlie the normal bones of the skull."

The eye-muscle canal or the myodome is said to be completely absent in *Siluridæ*. It is absent in all the forms under consideration, except in the primitive *Silundia* in which a definite, though very small, vestige of the myodome persists between the prootics and the parasphenoid and basioccipital. This clearly indicates that the myodome was well developed and functional in the ancestral forms of the Siluroids.

The extent to which the hinder portion of the cranium is excavated and the supraoccipital process developed may be taken, more or less, as a measure of advancement, since in the Pre-Cretaceous bony fishes the back of the cranium is nearly flat and the supraoccipital process absent (Woodward). There is no well-defined posterior surface in the cranium of the primitive *Silundia* and *Wallago* and the cranium in these fishes slopes backwards from the posterior end of the frontals. But in all the other forms the posterior surface of the cranium is vertical and is slightly excavated and there is a broad and massive supraoccipital process which has developed in response to the dorsal trunk muscles for their attachment.

A remarkable degree of specialisation is reached in the higher forms (*Arius* and *Osteogeneosus*) in the firm articulation of the complex vertebra and the post-temporal with the cranium. Besides the normal attachment of the vertebral column to the skull through the centrum of the first vertebra, the complex vertebra is firmly united with the cranium by three secondary articulations also, *viz.*, through (1) the sub-vertebral process, (2) the transverse process of the IV vertebra with the epiotic lamellæ, and (3) the spinous process of the IV vertebra with the supraoccipital and the exoccipitals above the foramen magnum. In the primitive forms, however, the vertebral attachment is not very strong.

There has been some confusion regarding the number of pterygoid bones in *Siluridæ*. It is stated by Kingsley[11] that there is only one pterygoid (metapterygoid). The pterygoid bones—ecto- and metapterygoids—are present in all the forms under consideration. There is a small entopterygoid also in *Silundia*. The ectopterygoid is small and is firmly articulated to the anterior end of the metapterygoid in the primitive *Silundia* and *Plotosus*, and it is toothed in the former. In other forms the ectopterygoid is small and is detached from the metapterygoid being connected with it only by connective tissue. Kindred[10] has described a small ectopterygoid in *Amiurus catus*. The metapterygoid has moved upwards and articulates both with the hyomandibular and the quadrate.

Both the maxillary and the palatine have undergone a great modification. The former is reduced to a very small, edentulous bone which merely supports the maxillary barbel. The palatine has assumed a rod-shape and has moved considerably forwards losing its firm connection with the pterygo-quadrate bar.

The opercular bones are comparatively small and the operculum and interoperculum are constant elements in all the Siluroids. The suboperculum is said to be absent in this family. It is absent in all the forms except in *Plotosus* and *Osteogeneosus* in which there is a very minute rudimentary suboperculum. Mac-Murrich[12] states that the first branchiostegal ray represents the suboperculum in *Amiurus*. But the presence of a vestigeal suboperculum in some forms clearly shows that the branchiostegal ray cannot be homologised with the suboperculum. Moreover Kindred[10] has pointed out the presence of a small suboperculum in *Amiurus catus*.

While the skulls of lower forms (*Silundia* and *Plotosus*) retain considerable amount of persistent cartilage, those of the higher forms (*Arius* and *Osteogeneosus*) have undergone complete ossification except for a small sheet of ethmoid cartilage.

The parietal, opisthotic, symplectic and generally a pterygoid and suboperculum are absent from the Siluroid skull.

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LIST OF ABBREVIATIONS USED.

a. font.	..	Anterior fontanelle.
ALIS.	..	Alisphenoid.
ART.	..	Articular.
ART OP.	..	Articular surface for the operculum.
ART PT.	..	Articular surface for the post-temporal.
au ca.	..	Auditory capsule.
BL.	..	Basioccipital limb of the post-temporal.
BO.	..	Basioccipital.
csi.	..	Cavum sinus imparis.
D.	..	Dentary.
ECP.	..	Ectopterygoid.
ECT.	..	Ectethmoid.
EL.	..	Epiotic limb of the post-temporal.
EPL.	..	Epiotic lamella.
EPO.	..	Epiotic.

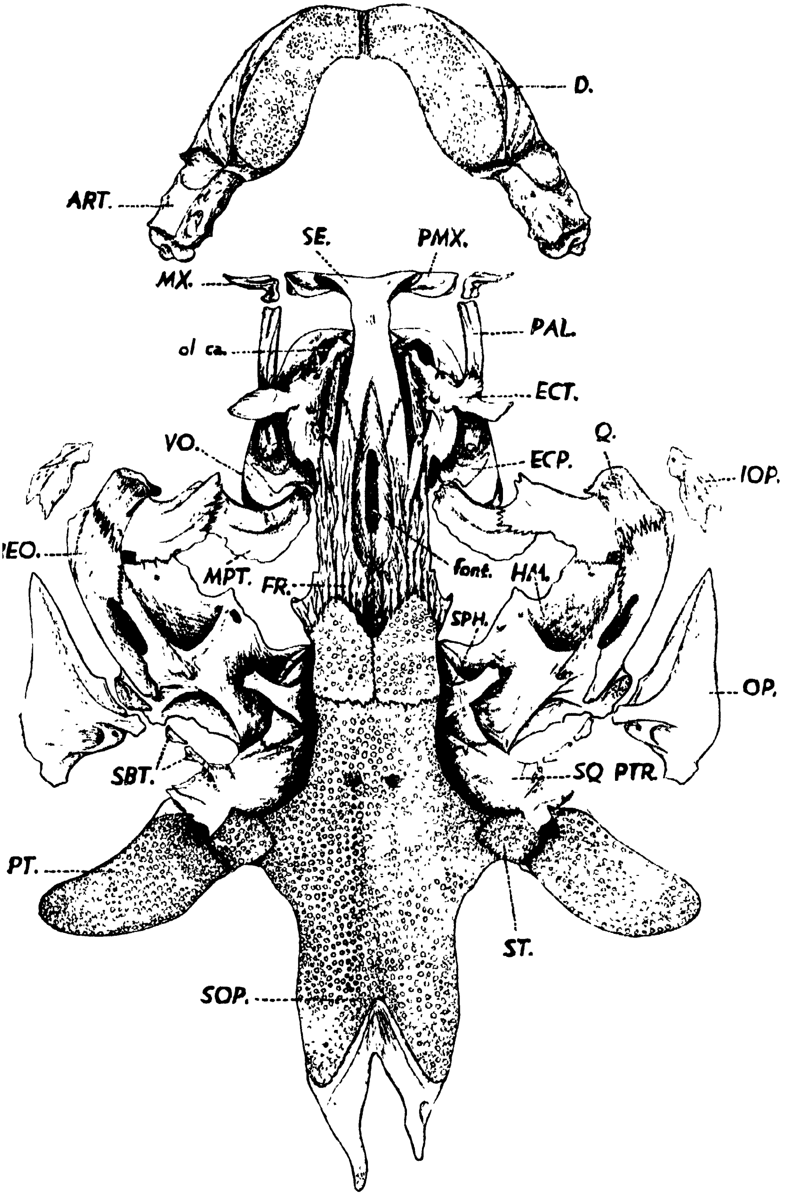
EX.	Exoccipital.
fmg.	Foramen magnum.
font.	Fontanelle.
FR.	Frontal.
HM.	Hyomandibular.
hypg.	Hypoglossal nerve foramen.
int s.	Internasal septum.
IOP.	Interoperculum.
IOR.	Infraorbitals.
LA.	Lacrymal.
MPT.	Metapterygoid.
MX.	Maxillary.
N.	Nasal.
ol ca.	Olfactory capsule.
OP.	Operculum.
OS.	Orbitosphenoid.
PAL.	Palatine.
p. font.	Posterior fontanelle.
PMX.	Premaxillary.
PREO.	Preoperculum.
PRO.	Prootic.
PS.	Parasphenoid.
PT.	Post-temporal.
ptf.	Post-temporal fossa.
Q.	Quadrate.
SBT.	Subtemporals.
SE.	Supraethmoid.
SO.	Supraoccipital.
SOP.	Supraoccipital process.
SOR.	Supraoccipital ridge.
SOSP.	Supraoccipital spine.
SPH.	Sphenotic.
SQ PTR.	Squamoso-pterotic.
SS.	Suprasphenoid.
ST.	Supratemporal.
sym. cart.	Symplectic cartilage.
t for.	Temporal foramen.
TRP IV VERT.	Transverse process of the IV vertebra
VO.	Vomer.
II.	Optic foramen.

V.	.. Trigeminal foramen.
VII.	.. Facialis foramina.
IX.	.. Glossopharyngeal foramen.
X.	.. Vagal foramen.

EXPLANATION OF FIGURES.

FIG. 1. The Skull of *Rita buchanani.* ($\times \frac{2}{3}$)
(The Suborbitals and the Lacrymals have not been shown.)
FIG. 2. The dorsal view of the Cranium of *Rita buchanani.* ($\times \frac{1}{3}$)
FIG. 3. The ventral view of the Cranium of *Rita buchanani.* ($\times \frac{1}{3}$)
FIG. 4. The lateral view of the Cranium of *Rita buchanani.* ($\times \frac{1}{3}$)
FIG. 5. The posterior view of the Cranium of *Rita buchanani.* ($\times \frac{1}{2}$)
FIG. 6. The median view of the bisected Cranium of *Rita buchanani.*
FIG. 7. *Rita buchanani* :—Side view of the anterior portion of the Cranium to show the Suborbitals, Lacrymal and the Nasal. ($\times \frac{3}{4}$)
FIG. 8. *Rita buchanani* :—Maxillary, palatine, pterygoquadrate bar and the lower jaw. ($\times \frac{1}{2}$)
FIG. 9. *Rita buchanani* :—The post-temporal. (Natural Size.)
FIG. 10. The Cranium of *Silundia gangetica.* ($\times \frac{1}{2}$)
FIG. 11. The Cranium of *Plotosus canius.* ($\times \frac{1}{2}$)
FIG. 12. The Cranium of *Wallago attu.* ($\times \frac{1}{2}$)
FIG. 13. The Cranium of *Pangasius buchanani.* ($\times \frac{1}{2}$)
FIG. 14. The Cranium of *Macrones aor.* ($\times \frac{1}{2}$)
FIG. 15. The Cranium of *Arius sona.* ($\times \frac{1}{3}$)
FIG. 16. The Cranium of *Arius sagore.* ($\times \frac{1}{2}$)
FIG. 17. The Cranium of *Osteogeneosus militaris.* ($\times \frac{1}{2}$)

PLATE I


D.
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SQ PTR.
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FIG. 1.

PLATE II

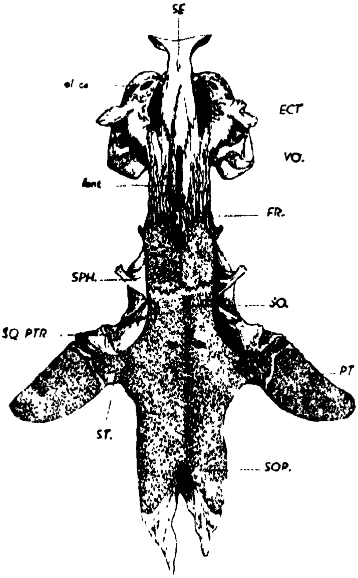


FIG. 2.

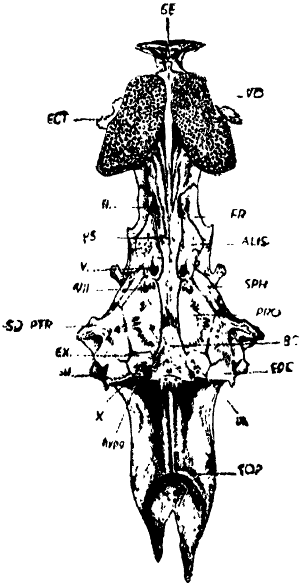


FIG. 3.

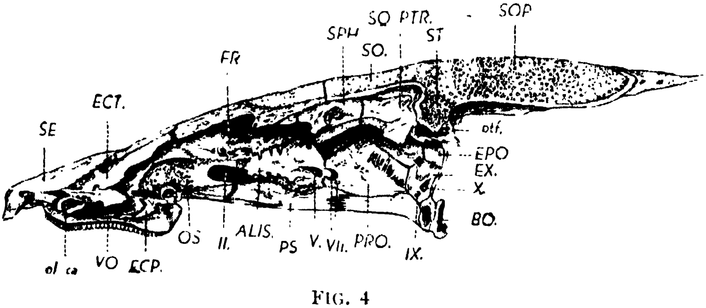


FIG. 4

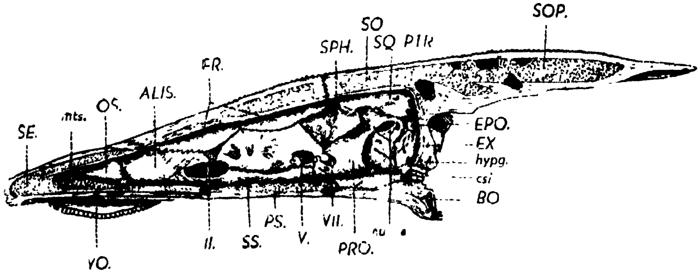


FIG. 6.

PLATE III

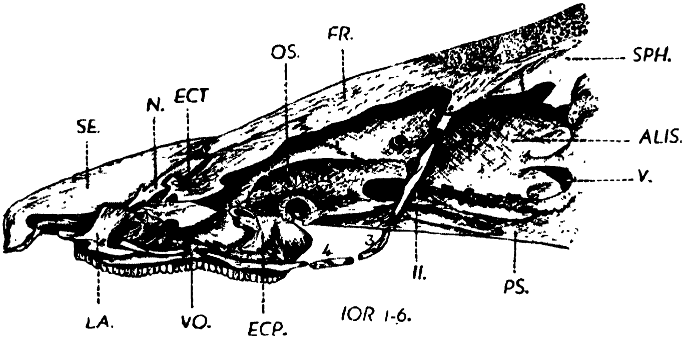
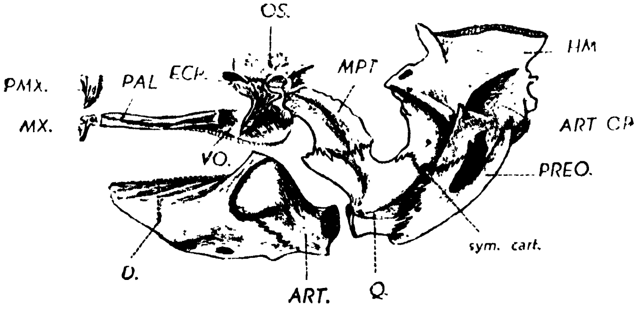


FIG. 7.



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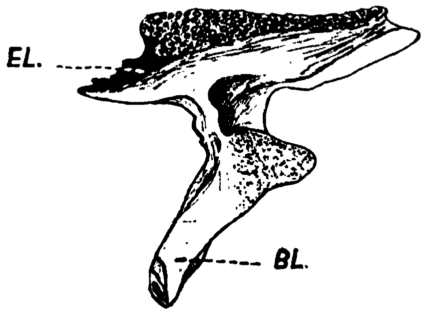

FIG. 9.

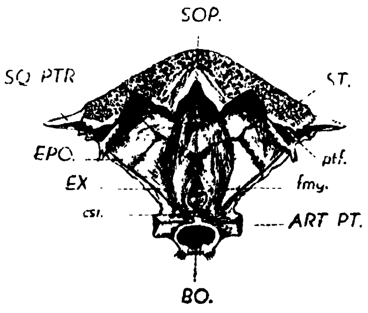

FIG. 5.

PLATE IV

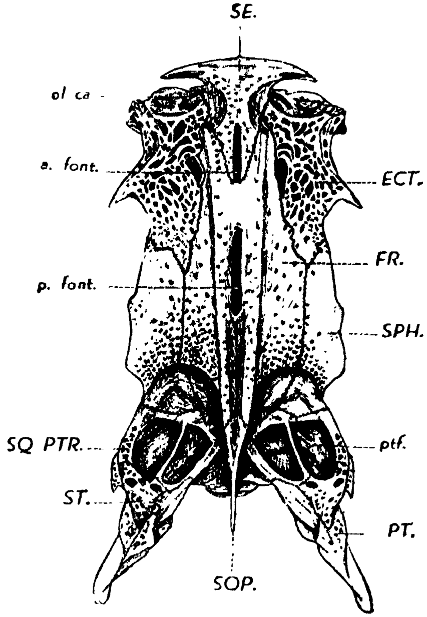

FIG. 10.

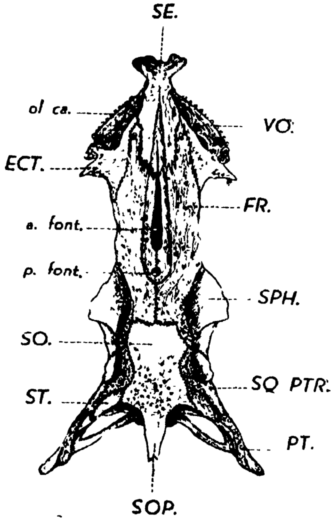

FIG. 11.

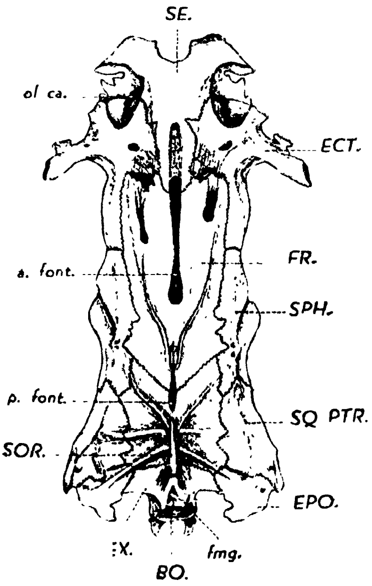

FIG. 12.

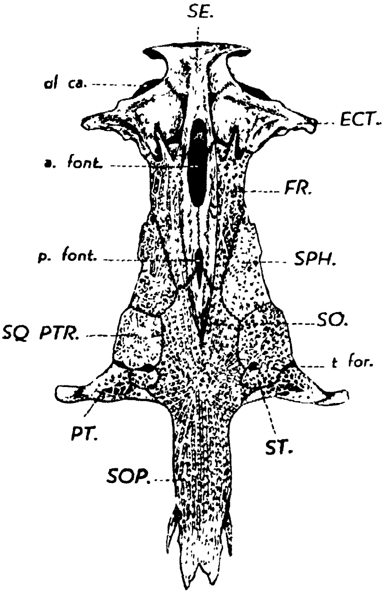

FIG. 13.

PLATE V

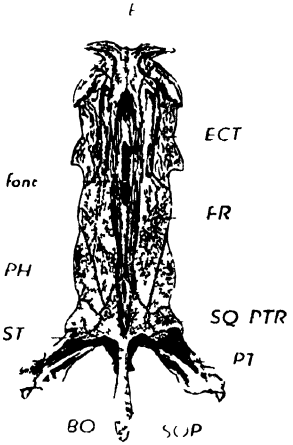

FIG. 14

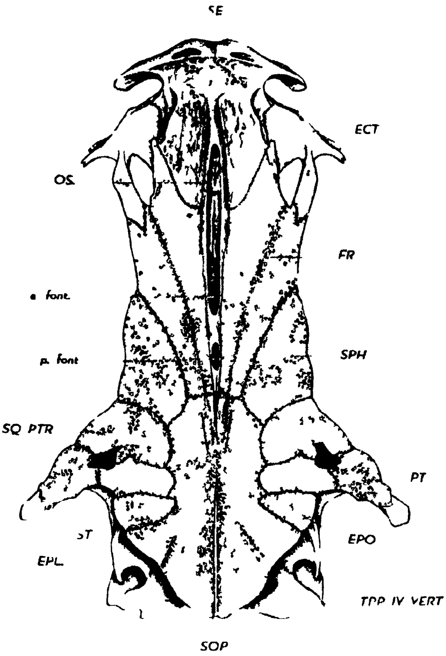

FIG. 15

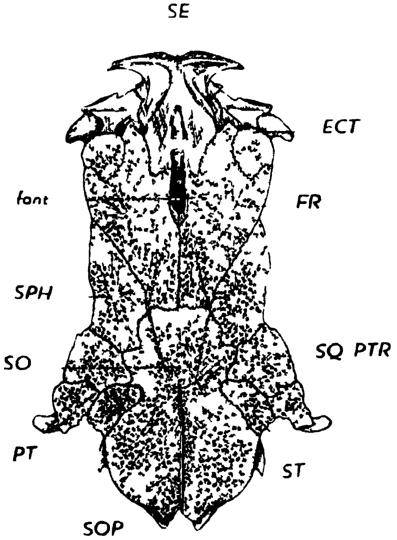

FIG. 16

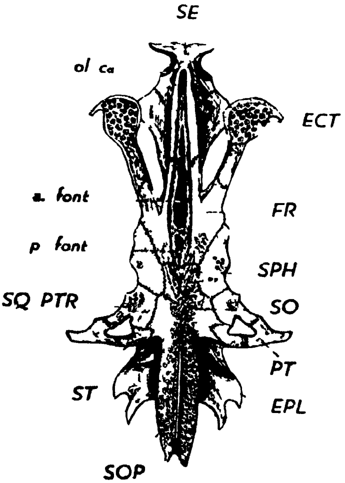

FIG. 17

REVIEWS.

MARRIAGE HYGIENE.

(VOL. I, NO. 1, AUGUST 1934.)

We welcome into the ranks of Indian Scientific Journalism the first issue of *Marriage Hygiene* edited and published by the co-operation of the leading members of the medical profession in India. The get-up of the journal, which is printed and published by the Times of India Press, Bombay, and the choice of the contributions are worthy of the objects which the editors have set before themselves.

The nineteenth century is marked by the great strides man has taken, as a result of scientific development, in the control of his environment and more particularly during the last fifty years the progress of biological sciences has emphasised man's solidarity with the rest of organic creation, both anatomically and physiologically. It is being increasingly recognised by statesmen and leaders of public thought that a schooling in biological sciences is a very necessary part of the equipment for good citizenship: hence any attempt to educate public opinion in this direction should be a welcome departure in the larger interests of our society.

"To secure for the science of conjugal hygiene a proper place in preventive medicine and publish contributions...... necessary for scientific and sane sex teaching" is the avowed aim of the *Journal*. Our society suffers largely because we have allowed to be governed by sentiment, age-old superstitions and traditions, never for a moment allowing the march of science to alter our social fabric or our general outlook on life. We have no hesitation in saying that a large measure of our domestic unhappiness and other social ills are due to our woeful ignorance of even the elementary fundamentals of biological science which govern our actions in every-day life. Our society generally taboos all knowledge of sex and sex-relations and looks upon the dissemination of such knowledge as highly objectionable, if not definitely criminal and has thus only succeeded in stimulating among the younger generation an unhealthy curiosity about sex and sex-life. In the absence of organised instruction in schools and colleges on this aspect of our life, the only other method to educate public opinion is by journalistic ventures such as the one under review.

Among the contributors to the *Journal* are some with international reputation and it is hoped that the *Journal* would, as suggested by Norman E. Himes, in due course enlist the co-operation of many more international figures whose ambition has been to strive for the betterment of humanity. The first issue has no doubt the disadvantage of a number of articles extracted from the published works of the authors but we are given the pleasant anticipation of original contributions from eminent men in the coming issues. Dr. Marie Stopes, the high-priestess of the cult of Birth-Control in the West, gives in an original article, a review of the several aspects of birth-control. The contribution of Julian Huxley is a very interesting and popular exposition of the biological aspects of human development. The article of Dr. Rele on the rôle of the uterus in Hysteria is, as pointed out in the editorial notes, thought-provoking and throws new light on the rôle of the uterus on the metabolism of the individual.

We wish the *Journal* a long and useful career.

JOURNAL OF THE MATHEMATICAL SOCIETY.

The *Silver Jubilee Commemoration Volume* of the *Journal of the Indian Mathematical Society* is just out. In the earlier pages will be found reports relating to the history and the progress of the Society. Founded in 1907 by Mr. V. Ramaswami Aiyar, M.A., the Society has now developed under an able and enthusiastic band of workers into the premier Society in India for the cultivation of mathematical study and research. It is interesting to note that the founder and several of its distinguished members and paper-contributors are men who are outside the teaching profession, but whose enthusiasm and love for mathematics are extra-ordinary and praiseworthy. Besides the publication of a journal, the Society has been rendering a very useful service through its Library, which lends mathematical books and periodicals to all members of the Society. Frequent conferences, arranged at different centres, have contributed very much to the popularity of the Society, and to group the mathematicians of the different provinces into one homogeneous association.

The *Jubilee Volume* which marks the completion of the quarter-century of the existence of the Society will be read with great interest by all mathematicians. The section devoted to original papers fittingly begins with a paper by Prof. G. N. Watson, F.R.S., who gives the proofs of some ten formulæ which the late Mr. S. Ramanujan, F.R.S., wrote down without proofs in his famous "Note-books". The *Jubilee Volume* has a number of interesting papers of a high standard, by different Indian mathematicians—a fact, which goes to show the enormous progress that has been made in India in recent years as regards mathematical study and research, and no small part of the credit for this goes to the Indian Mathematical Society. Amongst these papers, special mention may be made of papers by S. S. Pillai, by S. Chowla and by S. M. Shah on the Theory of Numbers, by K. Ananda Rau on Elliptic Theta Functions, by C. N. Srinivasiengar on Singular Solutions of Differential Equations, by B. Ramamurti and by S. Krishnamurty Rao on n-dimensional Mathematics, and by M. R Siddiqi on Heat Conduction in Wave Mechanics.

OBITUARY.

THE LATE PROFESSOR P. SAMPAT IYENGAR, M.A.

We deeply regret to record the premature death on Tuesday, 24th July 1934, of Mr. P. Sampat Iyengar, retired Director-Professor of Geology in Mysore. Born in the year 1879 the late Mr. Sampat Iyengar graduated with distinction in Geology from the Central College in the year 1900, and was almost immediately appointed a junior officer in the Mysore Geological Department, from which position he rose to be its Deputy Director in January 1920. In July of the same year when the Professorship of Geology in the Central College fell vacant on the retirement of Mr. V. S. Sambasiva Iyer, Mr. Sampat Iyengar was appointed University Professor of Geology, which office he held till he retired from service in June 1932. In the meantime, Mr. B. Jayaram, Director of the Mysore Geological Department, retired in 1927 and Mr. Sampat Iyengar was appointed also as the Director of the Department while continuing as Professor of Geology, and thus had the unique distinction of being the Director-Professor of Geology in Mysore for the years 1927-1932.

During the long period of his active association with the Mysore Geological Department, Mr. Sampat Iyengar made several valuable contributions to the study of the Archæan rocks of India in general and those of Mysore in particular. Regarding his work as a Professor of Geology, it is no exaggeration to say that the present leading position which the Geology section of the University occupies among similar institutions in India and the reputation which it enjoys as a centre of geological instruction and research is largely due to his untiring endeavours. In recognition of his eminence as a geologist, Mr. Sampat Iyengar was elected President of the Geology Section of the Indian Science Congress at Nagpur in 1920; and more recently, he was the President of the Geological, Mining and Metallurgical Society of India, Calcutta, for the year 1933-34. As a member of the Senate of the Mysore University, and of the University Council, Mr. Sampat Iyengar did valuable and useful service in the cause of University education in Mysore.

As a man Mr. Sampat Iyengar possessed a 'dynamic' personality and had an enormous amount of enthusiasm for work; and in all his actions, one could see his honesty of purpose and uprightness of character. He was always true to himself—in thought, word and deed. He was very simple and unostentatious in his manners and those that had the privilege of moving with him intimately knew what a good "friend, guide and philosopher" he really was. In his death, we have lost a rare type of a great personality, a great geologist, a learned professor and more than all—a genuine friend.

L. RAMA RAO.

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WITH PLATES AND FIGURES

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THE IRON FORMATIONS AND ASSOCIATED ROCKS OF THE EASTERN BABABUDANS, KADUR DISTRICT, MYSORE.

By Charles S. Pichamuthu, B.Sc., F.G.S., F.R.S.E.
(*Department of Geology, University of Mysore.*)

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1. INTRODUCTION.

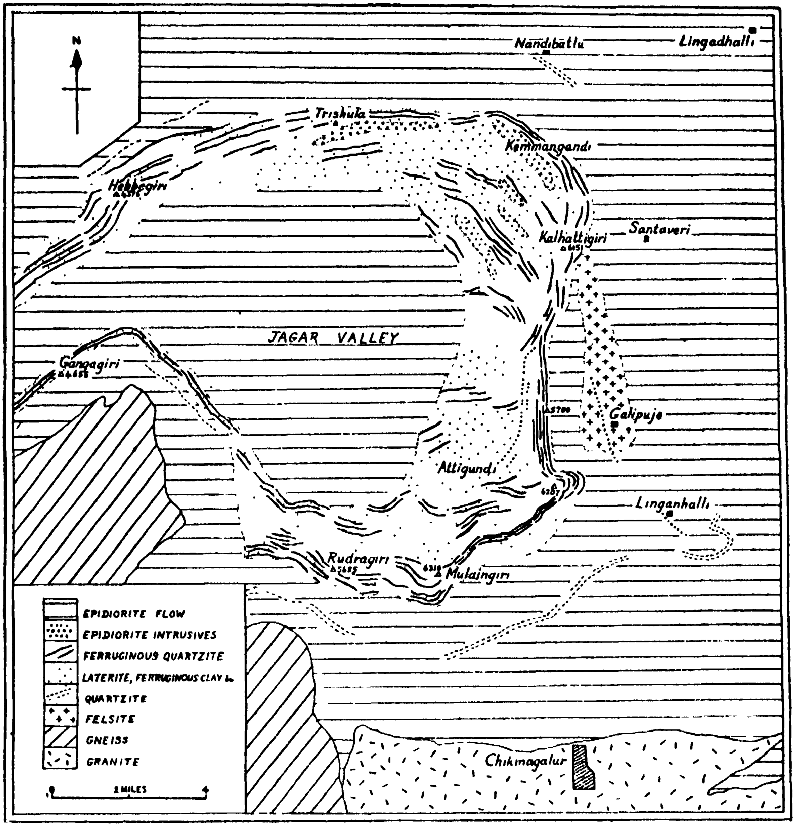
The oldest rocks of the Mysore State are the Dharwar Schists, which are comparable to the Keewatin formation of North America. They are largely composed of lava flows, associated igneous intrusions and their crushed phases. The

Dharwar System has been divided into a lower and an upper division on lithological and stratigraphical grounds. The lower division is formed essentially of rocks characterised by the presence of hornblende, such as hornblende schist and epidiorite; chlorite is common in the upper division which is composed of rocks such as chlorite schist and mica chlorite schist. Apart from the schistose rocks, the Dharwars also comprise conglomerates, banded ferruginous quartzites, quartzites and limestones, and all these rock types are considered in Mysore to be primarily igneous in character, though elsewhere similar rocks are usually assigned a sedimentary origin. According to Smeeth and Sampat Iyengar, two of the foremost workers on the geology of Mysore, these rocks have been probably formed from igneous material by metamorphic and metasomatic changes. Intruding into the Dharwar Schists are granites and gneisses of which several varieties have been recognised.

Constituting a part of the Shimoga belt of Dharwar Schists, the Bababudan Hills form a well-marked and conspicuous range in the Kadur District. They are disposed in the form of a horse shoe with the opening on the north-west at Hebbe; but this opening is partially closed and gradually tapers out towards the south. Because of its characteristic shape, the range is known in the vernacular as " *chandra drona* " which means " the crescent moon". The longer diameter of the more or less ring-shaped complex is about fourteen miles from east to west, and the shorter diameter nearly twelve miles from north to south. The crater-like centre within the ring is known as the Jagar Valley, which is well watered by the Somavahini river and its tributaries, the Tadavehalla and Wattehalla. The Somavahini does not originate in the Jagar Valley, but enters it through a gorge probably along a fault plane, between Malandur and Muttode.

The range varies in height from 4,000 to 6,000 feet, while the surrounding country has an average elevation of about 2,000 feet. It contains some of the loftiest peaks in the Mysore State such as Mulaingiri (6,310 feet), Kalhatti, Trishula, Hebbegiri and Rudragiri. The steep precipices, the thickly wooded valleys and the grassy slopes of the higher regions lend themselves to beautiful scenic effects (Plate I, Fig. 1). The lower slopes are covered with extensive coffee plantations.

An interesting feature of this range of hills is, that it is a place of pilgrimage for both Hindus and Mahomedans. One of the caves in Bababudan Peeta is supposed to contain the seat of Dattatreya according to the former, and the latter believe that it contains the tomb of the Mahomedan Saint, Bababudan, after whom the range has been named.



TEXT-FIG. 1.

Geological sketch map of the Bababudan ranges and its environs.

2. PREVIOUS WORK.

The earliest references to the geology of the Bababudan area, are found in the writings of Bruce Foote. His traverse notes from Jalarpet to Shikarpur (Foote, 1882, p. 195), and the report on the Dharwars of South India (Foote, 1888, p. 48), contain brief allusions. More detailed descriptions are given in his geological notes on traverses through the Mysore State (Foote, 1900, pp. 34–36). It was not, however, till 1908 that the problem of the banded ferruginous quartzites was seriously considered and the results of these studies are published in the reports by Dr. W. F. Smeeth (1908*a*, pp. 14–24), H. K. Slater (1908, pp. 54–56) and P. Sampat Iyengar (1908, pp. 74–76). The chemical and optical properties of the amphibole cummingtonite and the new species bababudanite, which were associated with the ferruginous quartzites, were also published in that year (Smeeth, 1908*b*, pp. 85–94). A geological map of the area was prepared jointly by Slater and Sampat Iyengar, and printed as Plate I in Vol. IX of the ***Records of the Mysore Geological Department.*** The economic aspects of the iron ores have been considered by Smeeth (1909) and Venkatramiah (1919, pp. 110–121). A brief account of the banded ferruginous quartzites is found in Smeeth's *Outline of the Geological History of Mysore* (1916, pp. 8–10).

3. GEOLOGY OF THE AREA.

The distribution of the different types of rocks occurring in this area will be seen from Text-Figs. 1 and 2. In this section, a brief description of these rocks is given; the relationships which these types bear to one another are considered in the next section.

Epidiorite Flows.—A large area to the east of the Bababudan ranges is covered by an epidiorite flow which has been described in the publications of the Mysore Geological Department as the Lingadhalli trap, Santaveri trap, Hornblendic lava, Hornblende schist and so on. The writer has examined these rocks from Chikmagalur to Lingadhalli and Nandibatlu, and finds that they are all epidiorites with only minor differences. The rock is chiefly composed of a pale green hornblende which is often fibrous. Plagioclase, when present, is of an acid variety. A little quartz is commonly present. Granular epidote is usually abundant; the mineral is sometimes idioblastic. Ilmenite occurs invariably altered to leucoxene.

In the map published by Slater and Sampat Iyengar in Vol. IX of the ***Records of the Mysore Geological Department,*** the epidiorites occurring to the south and south-east of the Bababudan ranges, have been differentiated into a coarse type and a fine type. The writer finds that the rocks here have undergone a low grade of dynamic metamorphism and that there is no well-marked boundary separating the coarse from the fine textured rocks. In the same map, the epidiorites to the north of the Avati river, have been given a separate colour and designated as "Hornblendic Schist and Trap". This distinction also seems unnecessary. The rocks on either side of the river are the same.

An analysis of a specimen of the epidiorite from near Santaveri, yielded results given in column II of Table I. The analysis is incomplete since H_2O+, H_2O- and CO_2 have not been determined.

The Mysore geologists were of the opinion that the epidiorite was not amygdular, but that the "spots" and patches present in it were due to crushing of quartz phenocrysts

(Slater, 1906, p. 12), or *in situ* alterations of porphyritic crystals of hornblende (Slater, 1908, p. 48). According to P. Sampat Iyengar, some of the "spots" were amygdular, some were due to the *in situ* alterations of plagioclase phenocrysts and some others were formed by the brecciation of quartz or epidote veins (Sampat Iyengar, 1908, p. 70). The writer has shown elsewhere (Pichamuthu, 1932, pp. 127-137), that all the spots occurring in the rock are truly amygdular, the vesicles being filled with minerals such as delessite, penninite, actinolite, epidote, zoisite, clinozoisite, quartz, pyrites, magnetite and calcite. Plagioclase felspars, derived probably from original zeolites, have been noticed in several of the amygdales near Lingadhalli (Pichamuthu, 1933, p. 345).

These epidiorites underlie the iron formations of the Bababudan Hills. A specimen selected at the foot of these hills immediately below the ferruginous quartzites, was analysed and the results are given in column I of Table I.

TABLE I.

	I	II
SiO_2 ..	56·10	51·82
Al_2O_3 ..	13·47	9·77
Fe_2O_3 ..	1·82	3·93
FeO ..	9·77	6·54
MgO ..	4·01	10·51
CaO ..	6·90	9·73
Na_2O ..	2·32	1·03
K_2O ..	0·74	0·16
H_2O + ..	2·40	n.d.
H_2O – ..	0·40	n.d.
CO_2 ..	nil.	n.d.
TiO_2 ..	1·80	1·51
MnO ..	0·16	tr
P_2O_5 ..	0·16	n.d.
	100·05	

I. Epidiorite, 7th Furlong, 30th mile on the Chikmagalur-Lingadhalli Ghat road. *Analyst*: W. H. Herdsman, Glasgow.

II. Epidiorite, Santaveri.

It will be seen that the silica percentage is high; this seems to increase as one approaches the banded ferruginous quartzites. This increase in quartz in the epidiorites is very noticeable in the Santaveri-Kalhatti section, as one ascends the hill. Near its junction with the ferruginous quartzites, the epidiorite grades on practically into a chloritic quartzite, though megascopically the difference is not quite apparent; it is appreciable under the microscope. This passage from an epidiorite to a chloritic quartzite is due to part of the materials constituting the latter being derived from the former.

Associated with these epidiorites, there are certain rocks characterised by the presence of laths of albite. They are sometimes doleritic in texture but often basaltic. No pyroxenes are present, the mafic mineral being chiefly chlorite, or in some cases, hornblende. These belong to a spilitic type.

The epidiorites and chloritic quartzites are succeeded by a bed of argillite and the ferruginous quartzites are laid over this.

Argillite.—These overlie the epidiorites and are immediately below the ferruginous quartzites. Very good occurrences of this rock are seen on the road sections near Kalhatti, by the side of the Kondekhan estate house, and on the 23rd mile on the Chikmagalur-Lingadhalli road, which was considered by Slater to be the type area for this rock. These rocks have been referred to in the ***Records of the Mysore Geological Department*** as aphanitic greenstones, and considered to be a glassy basaltic type. The writer has examined these rocks both in the field and in the laboratory and finds himself unable to accept that they are basic igneous rocks. They sometimes occur as thin intercalations and show very fine bandings. The rock is dark in colour and mixed with abundant ferruginous dust. When altered, it is converted into a yellow ochreous material. There is practically no grit. The exposures of this rock near the Kondekhan estate house are highly jointed, the joint faces being very smooth. The specific gravity of specimens collected here is 2·65; in other parts of the Bababudan Hills the writer has observed a range in specific gravity between 2·51 and 2·75. Slides cut from this rock do not exhibit any basaltic character. The rock could be described as a mudstone or argillite.

The rock is normally soft but near igneous intrusions, it has been hornfelsed, with the result that it has become extremely compact and tough, the fractures suggesting a glassy rock. The toughness is due to the development of mica or hornblende with the typical decussate structure characteristic of a hornfels (Plate II, Fig. 3).

Schists.—Interbedded with the iron formations occur chlorite schists, mica chlorite schists, talc schists, tremolite schists and actinolite schists. Almost all these types of schists are met with near Mulaingiri. They are as a rule considerably weathered and hence it is exceedingly difficult to prepare sufficiently thin microsections. They often exhibit strain slip cleavage. The schists are greenish in colour, but altered into yellowish and reddish ochreous material. Good contacts between the schists and banded ferruginous quartzites are very rare but the writer observed quite a satisfactory one near the 6th furlong of the 2nd mile on the branch road leading to Bababudan Peeta. This is as good a contact as one could expect in this region. Resting on the top of one of the hematite quartzite bands, there is an outcrop of schist. The contact is fairly sharp and there is no gradation from one rock to another, but the top of the hematite quartzite has thin layers of intercalated schist, and pyrites have developed at the bottom of the schists. Another fairly good contact was noticed on the same road near the 4th furlong of the 4th mile. The schist here contains numerous crystals of magnetite and pyrites and the hematite quartzite has a few thin micaceous layers. Since the dip of the beds in this place is almost vertical, it was not possible to determine which was the overlying bed.

Felsite.—To the east of the Bababudan ranges, there is an area of about 10 square miles which is occupied by a dark compact rock. Apart from a mere mention of the occurrence of this rock, no petrological description has been given in the *Records of the Mysore Geological Department*. Under the microscope, the rock is seen to be composed of abundant granoblastic quartz with flakes of biotite arranged as in a schist. The slides are peppered with minute grains of magnetite. Idiomorphic crystals of albite are common ; they are sometimes broken. These crystals are often bordered by biotite. Apatite in acicular crystals occurs as an accessory. The rock is allied to a keratophyre.

The chemical analysis of a specimen of this rock is given in column I of Table II. A and B are analyses of felsites from Scotland. B is allied to keratophyre and contains porphyritic crystals of albite-oligoclase replaced by calcite and chlorite, in a microlithic to patchy felsitic matrix composed of alkali felspar and quartz with chlorite and magnetite. This description agrees well with the Galipuje rock. P is an analysis of a specimen collected by A. M. Sen from near the Sulekere tank, which is further north in the same Shimoga schist belt. He calls it " Quartz Porphyry " and has given the following description which corresponds very closely to the Galipuje felsite. " These rocks consist essentially of porphyritic crystals of quartz and felspar or either of them embedded in a cryptocrystalline to microcrystalline groundmass of the same minerals. The principal ferromagnesian constituent is biotite which sometimes occurs in large crystals and sometimes in small

TABLE II.

	I	A	B	P
SiO_2 ..	70·60	70·70	69·48	72·73
Al_2O_3 ..	11·50	11·78	11·99	10·57
Fe_2O_3 ..	3·02	1·32	2·54	5·80
FeO ..	3·16	3·45	2·46	
MgO ..	0·12	0·53	1·16	0·98
CaO ..	6·90	1·30	1·72	2·19
Na_2O ..	3·26	2·48	3·33	3·09
K_2O ..	2·23	4·71	4·01	2·71
$H_2O +$ ..	1·00	1·14	1·56	
$H_2O -$ ..	0·50	0·50	0·32	
CO_2 ..	0·90	0·51	1·34	
TiO_2 ..	0·58	1·27	0·14	1·07
MnO ..	0·14	0·07	0·20	0·40
P_2O_5 ..	0·10	0·26	0·08	
S ..		0·08		
FeS_2 ..			0·05	
	100·11	100·10	100·38	99·54
Sp. Gr. ..	2·74			2·73

I. Felsite, Galipuje, Kadur District. *Analyst*: W. H. Herdsman, Glasgow.
A. Felsite, South of Coire Buidhe, Mull, Scotland. *Analyst*: F. R. Ennos. (Bailey and Clough, 1924, p. 20.)
B. Felsite, allied to keratophyre, North of Lennoxtown, Stirlingshire, Scotland. *Analyst*: E. G. Radley. (Clough, 1925, p. 185.)
P. Quartz Porphyry, West of Sulekere Tank, Shimoga District, Mysore.

grains and prisms.... It is found to alter to chlorite occasionally" (Sen, 1916, p. 153).

Banded Ferruginous Quartzites, Iron Ores.—The banded ferruginous quartzites overlie the Lingadhalli and Santaveri epidiorites and some of these beds are separated by varieties of schists. The iron ores are derived from the ferruginous quartzites. These rocks will be described in greater detail later. The iron formations have been subject to pressure and hence are folded and faulted. Bedded itabirite, composed of micaceous flakes of hematite with variable amounts of quartz, and showing perfect schistosity, has been formed by pressure; it is similar to the lustrous hematite-quartz schists, which have been produced by shearing from the banded ironstones of the Pretoria Series on Boven and Onderste Zeekoe Baard in Griqualand West (du Toit, 1926, p. 105).

Quartz Veins.—Veins of quartz often traverse the rocks of this area. Several of these veins contain acicular tourmaline; when they are numerous, the veins assume a dark colour. The tourmaline is sometimes aggregated in nests adjoining these veins as is well seen near the 22nd mile on the Chikmagalur-Lingadhalli ghat road.

Epidiorite Intrusives.—The banded ferruginous quartzites of the Bababudans are intruded by sills and dykes of quartz dolerites, which are now epidioritised. These rocks have been wrongly identified and described in the publications of the Mysore Geological Department as "Diorite Porphyry," presumably because of the occurrence of prisms of hornblende in them. A microscopic examination of thin sections reveals the secondary character of the hornblende which exhibits sieve structure. The texture of the rock is ophitic. The felspars are albitised. Plates of ilmenite altering to leucoxene are common. The chemical composition of the epidiorite can be seen from the first analysis in Table III. A and B are analyses of quartz dolerites described by Dr. G. W. Tyrrell from Arran and with which the Mysore rock agrees very closely. Under column P is given the average chemical composition of the basic Keewatin greenstones which are intrusive into the Lake Superior iron-bearing formations of the Gunflint District, and which have been described as metadolerites and metabasalts by Clements (1903).

Effects of the Intrusion.—One of the effects of the intrusion of the epidiorite is seen in the induration of the hematite quartzites which have become highly compacted and hence very tough. The banding of the rocks has been emphasised, and the ironstones in the neighbourhood recrystallised. Hematite has been converted into magnetite. It may be pointed out that Sir Thomas Holland has already suggested that magnetite has resulted from metamorphism of hematite in the banded quartzites of the Dharwar System, of the Salem District south of Mysore (Holland, 1900, p. 115). Observations made in the Bababudan area make it clear that magnetite is predominant in the ironstones near the epidiorite intrusions, and hence its origin is directly traceable to the influence of thermal metamorphism. A similar modification by later igneous action has been noticed in Southern Utah where limonite and hematite are deoxidised, to yield coarsely crystalline magnetite and some hematite (Leith and Harder, 1908, p. 80). The formation of magnetite by contact action has also been seen in the oolitic ironstones of the Daspoort horizon in South Africa. These ironstones show abundant development of magnetite crystals where they come within the contact aureole of the Bushveld complex, whereas such crystals are normally

TABLE III.

	I	A	B	P
SiO_2 ..	54·40	54·52	54·00	52·16
Al_2O_3 ..	14·27	14·53	13·09	16·77
Fe_2O_3 ..	2·35	2·21	3·53	3·92
FeO ..	9·50	6·06	8·45	5·44
MgO ..	5·75	5·61	3·49	5·20
CaO ..	4·90	8·08	5·55	6·23
Na_2O ..	2·94	3·66	3·27	2·58
K_2O ..	1·92	1·14	1·80	1·39
H_2O+ ..	2·10	0·93	1·71	3·28
H_2O- ..	0·20	1·95	1·26	
TiO_2 ..	1·20	0·87	2·83	0·45
P_2O_5 ..	0·10	0·21	0·31	0·16
MnO ..	0·25	0·24	0·37	..
CO_2 ..	..	..	0·25	2·14
S ..	tr	..	..	..
FeS_2 ..	..	..	0·14	..
BaO ..	..	0·02	0·02	..
	99·88	100·03	100·07	100·00

I. Epidiorite, Kemmangandi, Bababudan Hills. *Analyst*: W. H. Herdsman, Glasgow.

A. Quartz dolerite, dyke, Arran. *Analyst*: E. G. Radley. (Tyrrell, 1928, p. 254.)

B. Quartz dolerite, sill, Arran. *Analyst*: E. G. Radley. (Tyrrell, 1928, p 147.)

P. Keewatin greenstone, average composition. (Zappfe, 1912, p. 149.)

absent (Wagner, 1928, p. 83). Another example may be quoted from Ardnamurchan, Scotland, where a Liassic ironstone has been converted to magnetite (Richey, 1930, p. 43).

The most conspicuous example of change ascribable to the intrusion of the epidiorite, is in the development of amphiboles like bababudanite and cummingtonite. These minerals were considered by Smeeth and Sampat Iyengar to be original, and by their decomposition the hematite quartzites were supposed to have been formed; but recent field examination by the writer has shown that these minerals are present only in zones near the contact of igneous intrusives. This will be discussed in greater detail while dealing with the probable mode of origin of the banded ferruginous quartzites.

4. STRUCTURE OF THE AREA.

The earliest classification of the rocks of this and the adjoining Tarikere area was made by P. Sampat Iyengar. He divided the rocks into two series, the Bababudan Series and the Tarikere Series. He has divided these series further as follows :—

Bababudan Series—

Lava flows.—

- (i) Green Trap Hornblende Schist.
- (ii) Amphibolite.
- (iii) Brown Mica Chlorite Schist.

Probably intrusive sheet or sill.—

- (iv) Amphibolites and Peridotite, including altered representatives like talc-serpentine rocks.

Altered lava flows.—

- (v) Hematite Quartzite, Banded Quartz-Magnetite rocks, Hematite and Limonite Schists (derived chiefly from the alteration of bababudanite and cummingtonite).

Tarikere Series.—

Intrusive into Bababudan Series.—

- (i) Felsites, Porphyries and Biotite Gneisses which alter into
  - (*a*) Calc-chlorite Schists (Keratophyres);
  - (*b*) Siliceous talc sericite Schists;
  - (*c*) Crush Conglomerates.
- (ii) Diorite Porphyrite.

The Quartzites, Gneisses and the Dolerites are intrusive into both the Tarikere and Bababudan Series.

The numbers in the above classification do not represent any order of superposition. The only inference regarding age that we can draw from this scheme is, that the Tarikere Series is younger since it is intrusive into the Bababudan Series.

The writer differs from the above views regarding the mode of origin assigned to some of these rocks. As the sequel will show, he does not consider the hematite quartzites as altered lava flows. The writer has given evidences elsewhere that the "Crush Conglomerates" of the Tarikere Series were not formed by pressure on an igneous intrusive, but that they are of an original sedimentary nature (Pichamuthu, 1935 *b* and *c*). The writer agrees that the Tarikere Series is younger than the Bababudan Series, not because of its intrusive character, but considering the stratigraphical sequence.

Pebbles of almost all the types of rocks characteristic of the Bababudan Series are found in the Kaldurga conglomerates.

The ferruginous quartzites occurring in Mysore are supposed to be confined to the upper chloritic division of the Dharwar System. For the sake of those not familiar with Mysore geology, it may be stated that the term "upper" does not mean "younger," as the lower hornblendic division is considered to be intrusive into the upper chloritic division (Smeeth, 1926 *a*). Even where the ferruginous quartzites are associated with hornblendic schists as in the Kolar schist belt, they are believed to be patches caught up by the intrusive hornblendic rocks and not associated members of the Hornblendic division. The writer considers it probable that in Mysore the hematite quartzites are developed both in the hornblendic and chloritic divisions of the Dharwars. In the Bababudans, the epidiorites occur below the iron formations in the east, and are found overlying them in the west near Hebbegiri. Smeeth considers these rocks as intrusive and he is of opinion that the dykes near Kemmangandi are only the "more massive members" of the Lingadhalli epidiorites. According to the writer, the Lingadhalli and Santaveri traps are flows earlier in age than the banded ferruginous quartzites and that the dykes and sills near Kemmangandi and Virupakshikan are distinctly later intrusives into these ironstones.

The iron formations are generally confined to the higher regions of these ranges and furnish precipitous and almost vertical escarpments, often more than 100 feet in height, on the outer margin of the hills. The dip of the banded ferruginous quartzites is least at the north-east corner of the ranges and gradually increases towards the south and west. Near Kalhatti, the dip is about 20°, though in some parts the beds are almost horizontal. Along the northern side the dip increases to 40° or 50°, and in the western portion near Hebbe, it is about 60° or 70°. Along the eastern scarp the average dip is low, but in places as on the 6th furlong of the 29th mile, near Kemmangandi, the dip is vertical. The strike of the banded ironstones coincides practically with the trend of the ranges. The thickness of the beds averages between 200 and 300 feet.

The high angles of dip and the intensely folded and crumpled nature of these quartzites are evidences of the great disturbances to which these rocks have been subjected. The complicated tectonics of this area has not yet been satisfactorily worked out, as geological work on these hills is heavily handicapped by the dense jungles infested with wild animals, and the thick soil cap which obscures the disposition and relationships of the rocks.

5. THE IRON ORES.

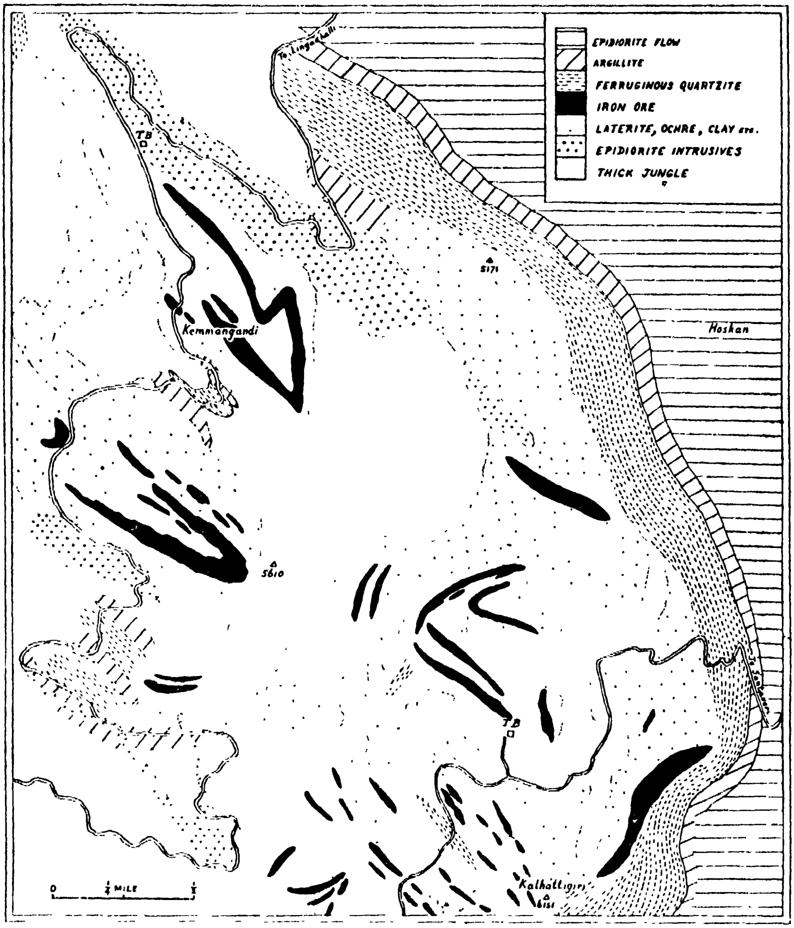
In the publications of the Mysore Geological Department, the term " Iron ore " has been used to denote both the economically important deposits as well as the banded ferruginous quartzites. In the present report, this term will be confined to the secondary concentrations of the oxides of iron derived from the ferruginous quartzites and which are rich enough to be used as an ore of iron. Smeeth made magnetic concentration tests on the magnetite quartzites occurring near Attigundi, in which the bands of quartz and iron ore averaged half-an-inch or more in thickness and appeared to be fairly cleanly separated. The results were, however, very unsatisfactory and discouraging, and these rocks were therefore considered unsuitable to be used as an ore of iron (Smeeth, 1926, pp. 52–56).

(*a*) Description.

Lateritic Ore.—The surface of the iron formations is invariably covered by a deposit of laterite which is often rich enough to be worked as an iron ore. The Bababudan Hills form the highest range in the Mysore State and hence intercept effectively the moisture-laden monsoon winds, and the consequent heavy rainfall is an active agent of denudation. The hill tops are either grass-covered or bare, so that there is little to protect the laterite, which is usually not of great thickness. The laterite occurs in slag-like masses containing numerous irregular tubular hollows coated with layers of brownish limonite. It is mixed with clayey and sandy material, the former commonly predominating. Sometimes, the laterite is composed of loosely aggregated pisolitic nodules, held together by clayey material.

Some of the laterites occurring near Kalhatti and Kemmangandi are bauxitic and contain 50 to 60 per cent. of alumina. These are considered to be lateritic modifications of the intrusive epidiorites which often alter into reddish lithomargic clays. Details regarding this deposit will be found in the *Records of the Mysore Geological Department* (Smeeth, 1917, pp. 38-40 ; Jayaram, 1919, p. 19 ; Venkatramiah, 1919, pp. 124-128) and in the *Review of Mineral Production of Mysore* (Sen, 1931, pp. 127-130).

Main Ore Body.—The main mass of iron ore is a non-lateritic deposit of hematite and limonite occurring on the dip slopes. It has not been possible to trace any definite relationship between the locus of the deposits and structural characteristics of the rock formations, as in some areas of the Lake Superior region where impervious basements and the presence of fractures have determined the location of ores. The deposits are bedded in places, and in part are composed of secondary depositions of hematite showing mammillary, botryoidal, stalactitic and other concretionary structures. Sometimes, the ore is composed of specular hematite, which might have formed as the result of load metamorphism or by hydrothermal action.



TEXT-FIG. 2.

Sketch map of a portion of the Bababudans, indicating the geology of the area and the distribution of the chief deposits of iron ore.

Kalhatti Deposit.—The ores near Kalhatti cover an area of about ten square miles and at a conservative estimate there are about 80 million tons of good ore. The following are a few analyses of the ore from this locality (Smeeth, 1909, p. 62). Prior to analysis, the samples were dried at 100° C.

TABLE IV.

	I	II	III	IV
SiO_2	0·76	3·63	0·77	2·17
Al_2O_3	3·03	6·56	9·82	7·95
Fe_2O_3	90·65	78·08	82·79	84·39
FeO	0·98	0·57	0·54	0·67
MgO	0·28	0·51	0·26	0·40
CaO	0·05	0·05	0·13	0·09
H_2O	4·06	8·34	6·09	4·98
P_2O_5	0·11	0·10	0·13	0·12
MnO	tr	1·04	0·08	tr
SO_3	0·08	0·13	0·12	0·06
	100·00	99·01	100·73	100·83
Fe	64·22	55·11	58·37	59·59
P	0·048	0·044	0·057	0·052
S	0·034	0·052	0·047	0·024

Kemmangandi Deposit.—Farther north, near Kemmangandi, there is a greater accumulation of high grade ore, and this is the site from where the ore is at present mined for the Mysore Iron Works at Bhadravati (Plate I, Fig. 2). The distribution of these ore deposits may be seen from Text-Fig. 2.

(*b*) Origin of the Ores.

The ores are associated with banded ironstones and occur as irregular masses. The ores have been formed from the ironstones through the agency of descending surface waters either by the leaching out of the silica and the deposition in its place of iron oxide or simply by the leaching out of the original siliceous layer without concomitant deposition of iron oxide. Quite conclusive evidence regarding the replacement of the silica layers by hematite, resulting in alternating bands of primary and secondary hematite, was not obtained, but proof of the removal of silica is common. At the time when the ores were formed, the siliceous layers of the newly formed rock were probably still composed very largely of comparatively easily soluble chalcedonic silica which would readily have been attacked by carbonated and alkaline circulating waters.

Geodal cavities lined with botryoidal hematite or with shining crystals of specularite are not uncommon. Some are probably of the nature of " volume vugs " (Irving, 1911,

p. 295), but many are just the remains of open spaces resulting from the folding and fracturing of the iron oxide layers. In some of the bigger cavities, the iron ores have a stalactitic habit with perfectly developed radiating structures in cross-sections.

In 1932, while examining the iron ore deposits, the writer came upon a specimen of fossil wood near Kemmangandi (Pichamuthu, 1935*a*, p. 510). It was found near the 6th furlong of the 27th mile on the Chikmagalur-Lingadhalli road. The road here has been cut along the sides of a hill, and it was from this cutting that the specimen was obtained. The hill, which is 4,500 feet above sea level, is composed of red earth containing lumps of iron ore.

The woody material has been completely converted into hematite. As the fossil was of a rather friable nature, it was with great difficulty that it could be sliced. The specimens and sections were kindly examined by Professor Walton, Professor of Botany in the University of Glasgow. Considering the imperfect preservation of the structures, he did not like to say more than that it was gymnospermous wood. Recently, specimens were sent to Dr. Sahni who agreed with Professor Walton's identification.

The iron ores have been, in part, segregated by the action of water. Some of the ores have undoubtedly accumulated in standing bodies of water, solutions having leached the iron from the ferruginous quartzites. This specimen of wood must have been washed into one of these sedimentation areas and had its woody material replaced by oxide of iron. There are, at present, no gymnosperms on these hill ranges.

The discovery of this fossil indicates that the accumulation of iron ore continued to take place during Post-Carboniferous and later periods.

6. THE BANDED FERRUGINOUS QUARTZITES.

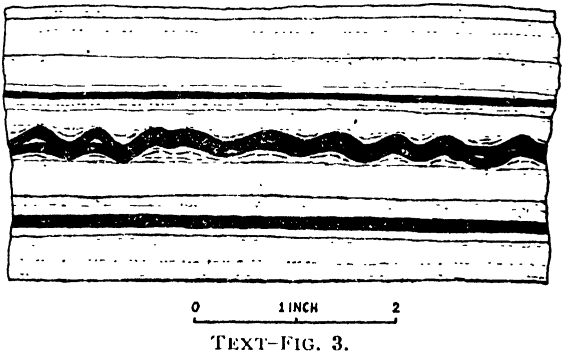
(*a*) Description.

The ferruginous quartzites vary in appearance and composition, often exhibiting great differences in the nature and thickness of their component bands, and in the relative proportions of ferruginous and siliceous matter. The colour and texture of the silica bands also vary considerably. They may be white, grey or various shades of red or brown ; and in texture they grade from that of a dense flinty chert or jasper irresolvable even with a lens, to that of a fine-grained saccharoidal quartzite in which the outlines of the individual grains can be made out with the naked eye. In weathered specimens, the quartz bands are very friable, and crumble easily into a fine white sand. The siliceous layers are sometimes formed of fibrous aggregates of quartz crystals, the fibres growing at right angles to the planes ot bedding ; it is possible to separate the fibres in certain cases.

Some of the laminæ in the ferruginous quartzite bands are composed wholly or predominantly of ferruginous or siliceous matter, but more often the layers are formed of intimately intermingled iron minerals and quartz, the iron oxides occurring in the form of crystals, grains or irregular patches, either scattered indiscriminately through a base of finely crystalline quartz, or, as is more common, concentrated in lines following the banding.

The ironstones sometimes exhibit conspicuous colour bandings, layers of black hematite or magnetite alternating with bands of red, pink, grey or white siliceous matter, when they are of strikingly handsome appearance. Such rocks have been designated " calico " rocks in South Africa. The bright red colours of the siliceous layers are found on microscopic examination to be due to small particles of oxides of iron.

The ferruginous layers are sometimes composed predominantly of hematite, occasionally accompanied by specularite. A little magnetite is often present. This mineral occurs almost to the total exclusion of hematite near igneous contacts. Near the surface, these minerals are converted into the hydrous oxide, limonite.



TEXT-FIG. 3.
Sketch of a Land Specimen of banded ferruginous quartzite illustrating interformational folding.

The bands are extremely regular and usually parallel. The writer observed that in some cases the bands were crumpled into minute folds while the bands above and below them were unaffected (Text-Fig. 3). Microsections cut from portions of such folded bands show that some of the thinner layers are broken (Plate II, Fig. 2). These are of the nature of interformational folds caused probably by submarine quakes during the period of deposition. The uppermost layers, if disturbed immediately after their deposition, would be thrown into a series of minute waves, while the slightly earlier formed lower layer which is now of harder consistency, would be brecciated. After the disturbance was over, the succeeding layers would again be normally deposited. These characteristics are well seen from Text-Fig. 3 and from Plate II, Fig. 2.

The relationship of the banded ferruginous quartzites to the underlying igneous rocks is not very clear, because the slopes are always covered by debris which bears thick vegetation. It has, however, been observed in some places that there is a gradual transition between the igneous rocks and the ironstones (Sampat Iyengar, 1916, p. 123). This was one of the reasons which influenced the Mysore geologists to consider the ferruginous quartzites as derived from igneous rocks. It is interesting to note in this connection, that a similar transition has also been observed in the Lake Superior region (Van Hise and Leith, 1911, p. 512). This will be considered later while discussing the mode of formation of the banded ferruginous quartzites.

(*b*) Mineralogy.

Quartz.—Silica occurs in large amounts and is now in the form of quartz. The mineral forms generally granoblastic aggregates. A mosaic texture with straight boundaries is common, but rarely the grains are seen to be interlocking with fimbriate margins. The grain size varies ; in the cherty layers, the grains are very minute but ordinarily they are much coarser. Some of the quartz layers are further laminated, each lamina having a different grain size. Streaks of iron ore inclusions often pass uninterruptedly through contiguous grains of quartz, and from this it may be inferred that the silica was originally deposited as a gel and later became crystalline.

The writer has collected from various parts of the Bababudans specimens of fibrous quartz (Plate III, Fig. 4). In some of the siliceous layers which are formed of fibrous aggregates of quartz crystals, the fibres are disposed at right angles to the plane of bedding and are separable in some cases. The fibres are not always straight, but often bent. These layers frequently exhibit a chatoyant lustre. In microsections, these quartz layers are seen to contain fibrous amphiboles. Though in no one place, it was possible to trace a layer of fibrous amphibole passing into a layer of fibrous quartz, the collections made by the writer show that the quartz has replaced the amphibole. The deposition of quartz in a fibrous form has been noticed in the crests of small-scale folds in the Triassic rocks of the Alps (Grubenmann and Niggli, 1924, p. 471), but in the Bababudans, this explanation cannot be adopted since the development of quartz is not confined to the crests of folds but is found in undeformed layers.

Similar fibrous quartz has long been known to occur associated with the banded ironstones of South Africa. Specimens collected by Lichtenstein were described by Klaproth (1815), who gave them the name "Faserquarz". Fuller details were published by Stow in England (1874), and by Cohen in Germany; the latter considered that the fibrous quartz was pseudomorphous after crocidolite (1873, p. 55). The pseudomorphous nature of the fibrous quartz was also maintained by Wibel (1873, pp. 367 *et seq*), but Renard and Klement were of a different opinion. They came to the conclusion that "les masses quartzeuses du Cap ne forment pas de pseudomorphose sur krokydolite, ainsi qu'on l'avait admis jusqu'ici, mais qu'elles ne sont autre chose que le résultat d'une infiltration de matière siliceuse, entre les fibres du minéral asbestiforme" (1884, p. 549). The prevalent view in South Africa is, that fibrous asbestos has been pseudomorphosed by silica (du Toit, 1926, pp. 106, 394).

Iron Ore Minerals.—Hematite is the common iron ore mineral occurring in the quartzites, so that most of the ferruginous rocks occurring in the Bababudans may be described as hematite quartzites. Magnetite occurs usually as minute octahedra, especially near intrusive contacts. It is abundant in the bababudanite-magnetite schists. Martite has been recognised in some places. These oxides of iron occur almost by themselves in certain bands but are often mixed with varying amounts of quartz.

Bababudanite.—This amphibole was discovered by P. Sampat Iyengar in the year 1907. He describes the mineral as occurring in radiating prismatic aggregates and in scattered patches having a strong pleochroism from Prussian blue to purple and yellowish green. According to him, the extinction angle is about 7° and the optical character of the mineral, positive. He considered it a variety of riebeckite rich in magnesia (Sampat Iyengar, 1908, p. 73). The same year, Dr. Smeeth got a chemical analysis made of this mineral from which he obtained the following formula:

$$2\ \mathrm{Na\ Fe\ (SiO_3)_2\ (Fe\ Mg_3)\ (SiO_3)_4}$$

Bababudanite was reported to occur only in the western portion (the Gangagiri branch) of these ranges by Sampat Iyengar. Jayaram observed the presence of this mineral in the neighbourhood of Attigundi (Jayaram, 1923, p. 41). In 1932, the writer obtained very good specimens near Kemmangandi and Kalhatti, on the eastern slopes of the Bababudans. The mineral is distributed sporadically in the ferruginous quartzites as well as concentrated in bands associated with quartz and magnetite.

Bababudanite is a shining black mineral with an almost adamantine lustre when quite fresh. It frequently appears dark brown in colour, but this is due to hematite or limonite which is deposited on the surface and along the cleavages. The crystals are prismatic with an acicular habit, sometimes occurring in fibrous bands (Plate III, Fig. 3) which are occasionally replaced by quartz. Perfect prismatic cleavages intersect at an angle of 124°. The specific gravity of the mineral is 3·31.

The analysis published by Smeeth totals only to 97·68 and so a new analysis of this mineral was made. The material for analysis was separated by the writer by hand picking, and since the mineral is very fine, it took nearly two months to collect just enough for a chemical analysis. The results of this analysis are given in column I of Table V. For purposes of comparison, analyses of crocidolite, rhodusite and crossite are placed alongside. The analysis of bababudanite published by Smeeth is given in column II.

TABLE V.

	I	A	B	C	D	II
SiO_2 ..	49·80	51·15	54·01	55·03	55·02	54·48
Al_2O_3 ..	1·56	—	0·23	0·49	4·75	2·10
Fe_2O_3 ..	18·62	14·92	15·70	15·47	10·91	15·79
FeO ..	10·59	9·80	9·42	7·39	9·46	5·02
MgO ..	9·30	10·80	10·01	11·48	9·30	12·11
CaO ..	0·45	1·12	1·52	0·98	2·38	1·04
Na_2O ..	8·80	6·52	6·22	6·38	7·62	6·34
K_2O ..	tr	0·63*	0·35	0·80	0·27	0·32
H_2O ..	0·65	4·77	2·25	1·98	—	0·40
MnO ..	—	0·30	0·14	—	tr	0·08
	99·77	100·01	99·85	100·00	99·71	97·68

I. Bababudanite, Kemmangandi, Bababudan Hills, Mysore. *Analyst:* W. H. Herdsman, Glasgow.

A. Crocidolite, Dochfour, Scotland. Quoted from Dana's *System of Mineralogy*, Sixth Edition, 1911, p. 400.

B. Rhodusite, Asskys River, Minussinsk District, Siberia. Quoted from *Journ. Chem. Soc.* 1908. Vol. 94, Abstracts Part II, p. 40.

C. Rhodusite, Rhodus Island. Quoted from First Appendix to Sixth Edition, of Dana's *System of Mineralogy*, p. 29.

D. Crossite, Berkeley, California. *Analyst*: W. S. T. Smith, *ibid.*, p. 20.

II. Bababudanite, Gangagiri branch, Bababudan Hills, Mysore. Smeeth, *Rec. Mys. Geol. Dept.*, 1908, Vol. IX, pp. 91-92.

The new analysis of bababudanite, except for a slight excess in magnesia, agrees fairly well with the formula:

$$4\ \mathrm{NaFe'''}\ (\mathrm{SiO_3})_2.\ 2\ \mathrm{FeSiO_3}.\ 3\ \mathrm{MgSiO_3}$$

The mineral differs from riebeckite in containing a high percentage of magnesia, and from glaucophane in its low alumina content. It resembles the analysis of crocidolite from Dochfour (A in Table V) fairly closely, but differs from this mineral in optical properties. The nearest approximation in both chemical and optical characters is to rhodusite. According to Isküll (1908) the composition of rhodusite may be expressed as an isomorphous mixture of two molecules, namely, $\mathrm{Na_2Fe_2Si_4O_{12}}$ and 5 $(\mathrm{Mg,Fe,H_2,Ca,Mn})\ \mathrm{SiO_3}$. The analysis which the writer has given above for bababudanite, if written in similar form would become

$$2\ \mathrm{Na_2Fe_2Si_4O_{12}},\ 5\ (\mathrm{Mg,Fe,H_2,Ca})\ \mathrm{SiO_3}$$

Smeeth's analysis corresponds to the following formula:

$$\mathrm{Na_2Fe_2Si_4O_{12}},\ 4\ (\mathrm{Mg,Fe,H_2,Ca,Mn})\ \mathrm{SiO_3}$$

The optic plane and Z are normal to 010. There is a strong dispersion of X, Y and optic axes. This dispersion and the intense pleochroic colours exhibited by the mineral, make accurate measurements difficult.

$(-)\ 2V$ = about 60°
$\gamma-\alpha$ = ·013 to ·014
$\beta-\alpha$ = about ·018
$X \wedge c$ = about 3°
X = dark Prussian blue
Y = yellow
Z = deep violet-blue

Cummingtonite.—This amphibole was first identified in Mysore in the hematite quartzites of the Kolar schists by Jayaram, and it is now known to occur in many of the ferruginous quartzites in various parts of the State. The mineral is rather rare in the area under investigation, but is more common in the Gangagiri branch of the Bababudans.

Asbestos.—The writer noticed bands of soft fibrous asbestos near the 2nd furlong of the 7th mile on the Chikmagalur-Lingadhalli road. The fibres are white in colour.

Crocidolite.—Bands of fibrous amphibole are common in various parts of the Bababudans. They are not easily separable into fine fibres and are sometimes replaced by quartz.

Pyroxene.—In the course of the writer's examination of the Bababudans, a yellowish or brownish green mineral was discovered near Kemmangandi as well as near Kalhatti. This is usually associated with bababudanite. It is a platy mineral with a sort of schiller lustre. It alters into a yellow ochreous material. The crystals are prismatic. The mineral is monoclinic with 110 cleavages and parting on 010. The prismatic cleavages intersect at an angle of about 90°.

The optic plane is parallel to 010. The mineral is pale yellowish green in thin sections and non-pleochroic. The mineral is optically negative.

(−) 2V = 82°
$\gamma-\alpha$ = ·042
$\gamma-\beta$ = ·018
$X \Lambda c$ = about 2° to 3°

A specimen of the mineral collected from near Kalhatti was analysed with the following results :—

TABLE VI.

	I	II	III
SiO_2 ..	52·75	51·35	52·22
Al_2O_3 ..	0·35	1·59	0·64
Fe_2O_3 ..	33·00	32·11	28·15
FeO ..	1·42	2·59	5·35
MgO ..	0·24	—	1·45
CaO ..	0·80	tr	2·19
Na_2O ..	9·70	11·39	10·11
K_2O ..	tr	tr	0·34
H_2O + ..	1·00		
H_2O − ..	0·50		
CO_2 ..	—		
TiO_2 ..	—		
MnO ..	—	0·37	0·54
P_2O_5 ..	tr		
	99·76	99·40	100·99

I. Pyroxene, Kalhatti, Bababudan Hills. *Analyst* : W. H. Herdsman, Glasgow.
II. Acmite, Rundemyr. Quoted from Dana's *System of Mineralogy*, Sixth Edition, 1911, p. 365.
III. Aegirine, Kangerdluarsuk, *ibid.*

The crystallographic and optical characters indicate that the mineral belongs to the pyroxene group. From Table VI it will be seen that in chemical composition it corresponds closely to acmite, but non-pleochroic acmite is very rare and has not been recorded except from the Hawaiian Islands (Washington, 1923, p. 107).

Pyrites.—Cubes and pyritohedra of this mineral occur especially in the metamorphosed zones. It is frequently pseudomorphosed by limonite.

Apatite.—Present in small quantities and with its usual properties.

(c) Amphibole-Magnetite Schist.

Intercalated with the ferruginous quartzites are thin layers of rocks which contain amphiboles like bababudanite. In some bands the amphiboles are present as a felted aggregate of fibrous crystals, and in others are more coarsely crystalline. Magnetite and quartz are present in varying proportions (Plate III, Fig. 2).

A specimen of bababudanite-magnetite schist was analysed and it will be seen from Table VII that it compares very

TABLE VII.

	I	A	B	C	D	P	Q
Fe	34·3	37·8	36·6	41·1	34·5	35·2	36·4
SiO_2	44·15	39·17	42·90	33·89	46·25	38·80	37·28
Al_2O_3	0·25	1·14	. .	1·15	0·92	0·20	0·40
Fe_2O_3	40·20	40·42	34·77	49·43	30·62	. .	. .
FeO	7·98	12·33	15·82	8·46	16·92	. .	. .
MgO	3·11	1·90	2·62	2·40	2·13	4·32	2·46
CaO	tr	1·37	1·33	3·16	1·69	2·55	2·35
Na_2O	2·60	. .	. .	. .	. .	. .	. .
K_2O	tr	. .	. .	. .	. .	. .	. .
H_2O-	0·05	2·56	0·47	1·50	0·42	. .	. .
H_2O+	1·60						
TiO_2	tr	. .	. .	. .	. .	. .	. .
P_2O_5	tr	tr	tr	. .	0·07	. .	0·05
MnO	. .	0·55	1·73	0·34	1·01	. .	. .
CO_2	. .	. .	. .	. .	. .	. .	. .
	99·94	99·44	99·64	100·33	100·03	. .	. .

I. Bababudanite-magnetite schist, Bababudan Hills, Mysore. *Analyst*: W. H. Herdsman, Glasgow.

A, B and C. Magnetitic slates, Wisconsin. (Irving and Van Hise, 1892, p. 197.)

D. Grünerite-magnetite schist, Michigan. *Analyst*: H. M. Stokes. (Van Hise, Bayley and Smyth, 1897, p. 338.)

P. Iron ore-amphibole rock, Badampahar Iron Mines, Noamundi, Singhbhum District, India. (Percival, 1931, p. 199.)

Q. Actinolite bearing recrystallised banded hematite silica rock, Badampahar. (Percival, 1931, p. 224.)

well with the amphibole magnetite rocks of the Lake Superior region.

The view that these amphibole-magnetite schists represent trap flows is suggested by Smeeth (1908*a*, p. 23) and Sampat Iyengar (1908, p. 72). They are supposed to be remnants of basic igneous rocks which by alteration have yielded the banded ferruginous quartzites. It will be seen from Table VII, that the analysis of bababudanite-magnetite schist bears no resemblance to an igneous rock ; on the other hand, it compares very favourably with the amphibole magnetite rocks occurring as intercalations in the Lake Superior banded ironstones of Michigan and Wisconsin, and which are considered to be of sedimentary origin. P and Q are partial analyses of somewhat similar amphibole bearing rocks from the Singhbhum District, India. In these two analyses, only the percentage of metallic iron has been determined and so to facilitate comparison, the percentages of metallic iron in the other analyses have been calculated.

It will be noticed that bababudanite-magnetite schist contains 3·11 per cent. of MgO as against a trace of CaO. The dominance of magnesia over lime is suggestive of a sedimentary origin. Van Hise and Leith consider that the Lake Superior iron-bearing formations must have been chemically precipitated because the average proportion of magnesia to lime is over 5 to 1 (1911, p. 506). A similar calcium-magnesium ratio has been observed in the Noamundi area by Dr. Percival (1931, p. 200), who is of opinion that these banded iron ores have originated as chemical sediments. The dominance of ferric over ferrous iron noticed in the bababudanite-magnetite schist, when considered in conjunction with the magnesia-lime ratio, strengthens the view that these rocks must have had a sedimentary origin (Grout, 1932, p. 432).

A striking point of difference which the analysis of the Mysore schist exhibits is in the presence of 2·60 per cent. of Na_2O. It has been mentioned earlier in this paper, that the rocks adjoining and underlying the banded ferruginous quartzites are many of them rich in soda, as may be seen from the prevalence of albite and acid oligoclase. The writer is of the opinion that the soda content of the bababudanite-magnetite schist is ascribable to the sediments being derived from these rocks of spilitic affinities.

The bababudanite-magnetite schists are often only about an inch or two in thickness, and are impersistent. They bear no resemblance chemically, mineralogically or texturally to the epidiorites of the area. Some of the bands of the ferruginous quartzites must have originally had different compositions, and the transformation of the bands by metamorphic agencies has produced different combinations of minerals. During recrystallisation, due to metamorphic differentiation, there is a tendency for minerals of the same kind to segregate, and that explains why some layers are rich in a single mineral, like bababudanite.

(*d*) Origin of the Ferruginous Quartzites.

According to Dr. Smeeth " the whole series appears to be conformable with the underlying hornblendic lavas and there is no suggestion either from field evidence or from microscopic examination that the banded quartz iron ore layers are of sedimentary character. On the other hand, a certain amount of evidence has been obtained which suggests that the iron ores are metamorphic alterations of some of the hornblendic flows." His reasons are mainly two, and they are here stated in his own words. " Evidence has been obtained showing a gradual increase of magnetite, usually accompanied by introduction or development of quartz in portions of the hornblendic lavas near the layers of quartz iron ore...... Some of the hornblendic beds which are of the nature of amphibolites appear to alter gradually into quartz iron ore rocks." He does not believe that the iron ores could be derived from the ferruginous clays with which they are associated, by a process of segregation. " It seems to me more natural to regard the iron ores as resulting from fairly deeply seated metamorphic action at a time when the present surface was buried beneath a considerable thickness of rocks of the same series or perhaps of some other series also. The result was probably the formation of several layers or beds of quartz magnetite rocks." (Smeeth, 1908, pp. 20–21).

Slater considered that the banded magnetite-hematite quartzites were produced through the " metamorphism and oxidation of the bands of amphibole that form the aphanitic greenstones " (Slater, 1908, p. 56).

P. Sampat Iyengar was of the opinion that the magnetite quartzites have been formed by the alteration of amphibolitic rocks containing cummingtonite and bababudanite (Sampat Iyengar, 1908, pp. 72–73 ; 1915, pp. 116, 123). Slater, working elsewhere in the Mysore State, did not, however, get clear evidence of the formation of magnetite from these amphiboles in the banded magnetite quartzites (Slater, 1907, p. 35), and Jayaram also doubted whether iron ores could be formed by this process (Jayaram, 1923, pp. 39–42).

Smeeth explained the mineralogical variations in the banded ironstones as follows: " Starting with a cummingtonite rock, it appears very probable that under the influence of thermal metamorphism, the mineral would tend to break up into oxide of iron and silica, and that these would recrystallise as magnetite and quartz, giving rise to some of the banded quartz magnetite rocks of Mysore with or without residual cummingtonite. It is probable that solutions containing silica take part in the transformation and increase the amount of quartz and that some of the cummingtonite get recrystallised during the process and that the various constituents frequently travel considerable distances from their original source. Hence we get all varieties from a pure cummingtonite amphibolite, to stages containing a little quartz and magnetite to the banded quartz magnetite rocks with a few small prisms of cummingtonite and finally to almost pure quartz rock on the one hand, and almost pure magnetite on the other hand" (Smeeth, 1908*b*, p. 87).

Very similar views have been adduced to account for the origin of the banded hematite quartzites in other parts of Mysore. The magnetite quartzites of the Western Ghats (Sampat Iyengar, 1912, p. 59), the ferruginous quartzites of the Bangalore District (Jayaram, 1901, p. 190), Kolar District (Smeeth, 1901, p. 23 ; Jayaram, 1910, pp. 178–79), Javanhalli Schist Belt (Wetherell, 1904, pp. 13–18), Hassan District (Sampat Iyengar, 1909, pp. 53–56), Tumkur District (Sen, 1912, p. 123), Shimoga District (Sen, 1916, p. 148), and of the Yemmabetta Range (Jayaram, 1917, p. 101), have all been explained as formed from the decomposition of cummingtonite.

While discussing the origin of the iron ores of the neighbouring Bhadravati-Joladhal region, V. T. Venugopal has offered quite a different suggestion. According to him, " the large quantity and great concentration of the iron oxides makes their formation from the rocks in which they are found somewhat improbable and leads one to doubt if they may not represent almost entirely introduced material, and the amphiboles either secondarily developed or remnants from the adjacent schists. Since the upper division of the Dharwars in Mysore consist of the Champion Gneiss Series, and two acid phases, *viz.*, the fine-grained intrusives and the intrusive granitic phase, have been recognised, and since in some phases the iron-bearing formations seem to be related to the acidic phases, it is to be doubted whether they may not be extreme differentiation products, on the analogy of the charnockite quartz magnetite rocks. One of the field evidences in support of this is, that the Champion gneiss granite, so far as has been observed by the writer, was not seen to intrude, cut through or hold as an inclusion, the type of the banded hematite quartzite of the Dharwar age. Again there are quite a number of types of the ferruginous quartzites, from those that contain a very small per cent of iron to those that are rich in it. These iron oxides are primary ores and not replacement ores and the way in which they occur point to their origin being simultaneous with the quartz which should have been the end phase of an acid magma " (Venugopal, 1924, p. 267).

In 1916, Dr. Smeeth left the question of origin open. " If the series is not of sedimentary or chemical origin, it is extremely difficult to find a satisfactory explanation for it on account of the completeness of the metamorphism and the difficulty of finding good contacts. It is not impossible that these banded rocks represent sills of highly ferruginous character, subsequently altered to quartz and magnetite or even, in some cases, sills of a quartz magnetite rock such as will be referred to later in connection with the charnockite series.... As to their sedimentary or aqueous character, definite proof is lacking, but the great consensus of opinion is in favour of such a view" (Smeeth, 1916, pp. 9, 10). The last sentence does not, however, refer only to Mysore, but to the banded ferruginous quartzites occurring elsewhere in the world.

His latest views on the subject were expressed in a lecture to the Geological Society of London where he makes no mention of the sedimentary origin but has suggested that some of the banded quartz iron ore rocks might be the metamorphosed relics of igneous rocks composed, in great measure, of highly ferruginous amphiboles (such as cummingtonites) or other chemically altered minerals (Smeeth, 1918, p. lxxxv). This is the official opinion of the Mysore Geological Department regarding the origin of the ferruginous quartzites, excepting for those associated with the charnockites, which are supposed to have been formed by magmatic differentiation (Jayaram, 1912, pp. 92–93 ; 1913, pp. 80–82).

In the latter part of the year 1932, the writer led an excursion of geology students of the Mysore University, and one of the areas visited was the Bababudan Hills. The well-known Kaltippur-Kemmangandi section was examined and the Santaveri-Kalhatti section which had not so far received the attention of geologists was carefully studied. As a result of this visit, it was noticed that the occurrence of amphibole minerals, especially bababudanite, was confined to zones in the immediate vicinity of igneous contacts (Pichamuthu and Srinivasa Rao, 1933, pp. 276–77). This discovery was of no small significance in the genetic considerations of the Bababudan iron formations and seemed to warrant a close study of the whole problem from a fresh point of view.

The amphiboles were quite fresh with very bright lustre excepting where they had been exposed to superficial weathering agencies. An important point in connection with their mode of occurrence was, that in many cases they were developed right across already existing bands in the quartzites (Plate III, Fig. 1), and so were formed decidedly after the ironstones had acquired their banded nature. Moreover, if the ironstones have resulted by the decomposition of such highly magnesia-bearing amphiboles such as cummingtonite and bababudanite, one has to postulate some cause for the almost total disappearance of the magnesia from the banded ferruginous quartzites, leaving behind only the iron and silica.

The association of iron-rich members of the amphibole group with ferruginous quartzites has been noticed in other parts of the Mysore State. In the Chitaldrug (Sampat Iyengar, 1905, p. 72), Tumkur (Sampat Iyengar, 1906, p. 51), Bangalore (Sen, 1912, p. 123), Shimoga (Sen, 1916, p. 148) and Mysore (Jayaram, 1917, p. 101) Districts, such occurrences have been described. Definite evidence of the metamorphic origin of the amphiboles in the ferruginous quartzites of the Kudremukha and Gangamula regions, Kadur District, has been obtained by Sampat Iyengar (1912, p. 61). A similar metamorphic development of amphiboles has been recorded from the Hassan District (Rama Rao, 1924, pp. 178–79) and elsewhere in the Kadur District (Smeeth, 1910, p. 44). In the Bangalore District, Sen found garnets in association with the amphiboles in the ferruginous quartzites.

Amphiboles like grünerite, cummingtonite and hudsonite occur in the iron formations of Madagascar (Lacroix, 1922, p. 535). In Africa, the banded ironstones have often been metamorphosed leading to the development of amphiboles (Wagner, 1928, p. 72). Similar phenomena are also noticed in the Vredefort Mountain Land, where the lower Witwatersrand Beds have been altered through the combined effects of static and contact metamorphism (Hall, 1925, p. 135).

Frequently, during Pre-Cambrian time, the iron-bearing formations of America were metamorphosed by igneous intrusion and one of the results was the formation of amphiboles. Numerous references to such occurrences are found in the publications of the United States Geological Survey. According to Richarz, perfectly crystallised amphiboles cannot form under even the greatest dynamic processes but high temperature is required which cannot be developed by mountain folding and faulting (Richarz, 1927, p. 697).

Source of Soda and Magnesia.—The analyses of cummingtonite and bababudanite contain a high percentage of magnesia while the latter mineral and the non-pleochroic acmite are soda-bearing. The analyses of the ores derived from the banded ironstones of the Bababudans near Kalhatti show that there is no trace of soda, but that there are small percentages of magnesia varying from 0·28 per cent to 0·51 per cent (*vide* Table III). The crocidolite found in the banded ironstones of South Africa contains soda varying from 3·90 per cent to 7·71 per cent. According to Hall, the source of this soda is an extremely difficult question to which no answer has so far been found satisfactory in every respect. He considers the soda to be original and dependent upon special conditions of deposition and the postulate of soda-rich layers in the ironstones appears to him to offer least objection (Hall, 1930, p. 252). Peacock in dealing with the problem of the origin of the amphibole asbestos in South Africa points out the three following possibilities: (i) soda may have been a foreign constituent introduced by travelling solutions; (ii) crocidolite may occupy the place of pre-existing soda-rich bands; (iii) soda may have been uniformly distributed through the ironstones and subsequently concentrated in certain bands. After discussing each of these suggestions, he favours Hall's conclusions (Peacock, 1928, pp. 271–72).

As has been suggested earlier in this paper, the writer considers that in the Bababudan area, certain layers in the ferruginous quartzites were originally soda-rich, the materials being derived from the disintegration of the adjoining spilitic rocks. Bababudanite and acmite have developed in these soda-bearing layers when they were sufficiently near igneous contacts.

In the two analyses of the South African ironstones published by Hall, the percentage of magnesia is seen to be 0·35 and 0·42, whereas crocidolite contains amounts ranging from 1·37 per cent to 4·55 per cent, and amosite from 0·74 per cent to 8·50 per cent. In several places in South Africa, the amphibole seams are found in close proximity to the underlying dolomites. This association is not likely to be purely accidental and indicates the dolomites as the probable source of the magnesia. In the case of the Lower Griqua Town Series, this genetic connection with the dolomites is less apparent, since the crocidolite veins seem to be spread out over a greater vertical range. Peacock (1928, p. 271) while discussing this question, is inclined to explain the magnesia in the amphiboles to local concentration and refers the greater abundance of crocidolite seams in the lower reaches of the ironstone formation to the higher temperatures which probably obtained at the lower horizons. This implies that the effects of igneous intrusion, whether direct or indirect, are mainly responsible for the transformation of ironstone into amphiboles.

Dolomites cannot be considered as the source of the magnesia in the Bababudan area because no magnesian limestones are found associated with the iron formations (unless the tremolite actinolite schists are considered to be metamorphosed magnesian limestones), though it might explain the occurrence of cummingtonite in the adjoining Bhadravati-Joldhal area, where dolomite underlies the ironstones. The writer is of the opinion that local concentration of the disseminated magnesia and the formation of the amphiboles by igneous intrusion, is perfectly in accord with the conditions pertaining to the occurrence of cummingtonite and bababudanite. Hall has clearly shown the genetic connection between the Bushveld intrusion and the formation of amosite in the Transvaal, and crocidolite in the Cape Belt (Hall, 1930, p. 255). In the Bababudans, the intrusion of dykes and sills of epidiorite is responsible for the formation of the amphiboles.

Amphibole-Magnetite Schists.—Reference has already been made to the intercalation of thin bands of fresh-looking distinctly recrystallised amphibole layers, containing magnetite. These have been considered up till now as representing trap flows or as remnants of amphibole schists which by alteration were supposed to have yielded the hematite quartzites. This view does not explain why such layers are, at present, found quite unaltered in the midst of the banded ironstones. Their thinness, their restricted horizontal extent, their grading into the underlying and overlying layers and their mineral and chemical composition are all against considering these amphibole layers as representing an igneous rock. They are formed by the thermal metamorphism of certain of the original layers in the ironstones.

Argillite.—The occurrence of a dark grey argillite has been observed in the ironstones. This rock, because of its compactness and jointed nature, had been mistaken hitherto for a glassy basaltic flow or sill. Its identification by the writer as an argillite, makes it difficult to account for its origin if the ironstones are considered to be metamorphic derivatives of an igneous rock, but is capable of explanation if the whole series is considered to be sedimentary.

Clay.—Deposits of reddish clay have long been known to be associated with the ferruginous quartzites of the Bababudans. They have been considered by some of the Mysore geologists to be formed by the alteration of trap intercalations. The same persons have also considered the fresh amphibole schists as unaltered remnants of traps. Acceptance of these views involves certain difficulties. The original trap rocks are supposed in part to alter into reddish clay, while some portions give rise to the banded ferruginous quartzites and others form the amphibole schists. The difficulty is increased when these types are seen to alternate, as they do sometimes.

Banding.—The perfect nature of the quartz and iron ore banding is a distinctive feature of the ferruginous quartzites of this area. This has been accounted for by postulating *lit-par-lit* injections of quartz veins (Sampat Iyengar, 1908, p. 76). It is difficult in this manner to account for the extreme uniformity and regularity of the bands over large areas: a satisfactory explanation has also to be given for the source of this quartzose material.

Under the microscope, the quartz layers are themselves seen to be banded, being composed of layers of different grain size, any single band containing fairly uniform grains of quartz. It was also noticed that the quartz layers contained lines of inclusion which passed without interruption through adjoining grains of quartz and which were themselves disposed parallel to the bedding planes. These features are evidences of crystallisation from an original gel (Boydell, 1925, p. 203).

Interformational Folding.—The presence of interformational folding in the ferruginous quartzites cannot be explained if these rocks are considered to be derived by the metamorphism of an original igneous formation. The occurrence of these folds is a very good proof that the layers were formed successively one after another as a sedimentary deposit.

Cross-cutting Veins of Quartz.—It has been observed that veins of quartz sometimes cut across the general direction of banding. The quartz of these veins is of different texture and contains coarsely crystallised hematite. Such an occurrence would suggest that these veins were of later injection. But Goodchild, in his contributed remarks on Boydell's paper on " The rôle of colloidal solutions in the formation of mineral deposits", explains such veins as follows: " By whatever process banded hematite quartzite is produced, suppose one called alternate bands, positive and negative. If there is any disturbance in such a process, most important results may follow. The rhythm may alter its direction, something like an eddy in a stream. Along a 'crack', actual or potential, in the matrix, positives and negatives work out abnormally across the normally parallel bands. The result is a cross vein of quartz of different texture " (Goodchild, 1925, p. 291). The occurrence of these cross-cutting veins of quartz does not therefore conflict with the sedimentary origin of the ferruginous quartzites.

Gradation between Igneous Rocks and Ferruginous Quartzites.—One of the arguments in support of the metamorphic origin of the ferruginous quartzites has been the gradation noticed in some places between the underlying traps and the ironstones (Sampat Iyengar, 1916, p. 123). It is interesting to refer in this connection to the similar transition observed in the Lake

Superior region. The Keewatin basalt shows a gradation phase through siliceous basalt into banded siliceous iron-bearing formation ; in several cases it has been practically impossible to draw a line between unaltered basalt and the iron formation (Van Hise and Leith, 1911, Plate XLVIII). The gradation, according to Van Hise and Leith, seems to be original, and has been adduced by them as an evidence to show that the associated iron ores of the basic igneous rocks are not later secondary replacements of such rocks, but that they were precipitated soon after the crystallisation of the igneous rocks. The silica is supposed to have been deposited under conditions differing radically from those observed to-day (Leith, 1910, p. 242).

The writer's observations on the Kalhatti section, which yields fairly satisfactory exposures showing the relationship of the banded ferruginous quartzites to the underlying rocks, indicate that the transition from the iron-bearing rocks to the epidiorites is not so gradual as has been suggested by Sampat Iyengar.

Greenalite.—The original rock from which the Lake Superior iron formation was derived is considered to be cherty iron carbonate and greenalite. No traces of any greenalite granules have yet been noticed in the Bababudan iron formations. It must, however, be remembered that greenalite is absent in the Biwabik Formation of the Mesabi Range of the Lake Superior field. Wolff believes that the bulk of the iron oxides in the Biwabik Formation is in the same " chemical state " now as that in which it was laid down (Wolff, 1917, pp. 233–35). Greenalite is not a very stable mineral, and it is likely that it was present and has subsequently altered. No greenalite has been observed in any of the South African banded ironstones but this according to Wagner " by no means disproves that it may have been originally present " (Wagner, 1928, p. 64).

Siderite.—Siderite was also not met with in the Bababudan area though its occurrence in the iron formations of the Chitaldrug District of Mysore has been recorded (Sampat Iyengar, 1905, p. 85). Evidences, however, of the former occurrence of a carbonate mineral may be inferred from the presence of areas exhibiting rhombohedral outlines (Plate II, Fig. 4). These are now composed of granular quartz but invariably there is difference in grain size between these areas and the surrounding matrix. In the South African ironstones, the chert layers show clear rhombohedral areas occupied by comparatively coarse-grained quartz, indicating that a carbonate has been leached out and its place taken by quartz. The carbonate itself is nowhere preserved, but it is surmised that the mineral is siderite (Wagner, 1921, p. 120). Similar features have also been noticed in Noamundi but, according to Dr. Percival, the carbonate is dolomite (1931, p. 224). In the Bababudans, these rhomb-shaped areas are often surrounded by zones of iron ores and hence it is likely that the original mineral was siderite.

Dolomite.—The association of the banded quartzites and dolomite can be interpreted as indicating that the cherts were of marine origin. The Bababudan ironstones do not occur with dolomite, but in the neighbouring Gangur-Joldhal area, the ironstones are overlying dolomites, and cummingtonite has also developed. Though the iron ore deposits of these two areas are now isolated, there is no doubt that these once formed one continuous exposure. It may be that the calcareous sediments were confined to one portion of the sedimentation basin and the ferruginous material followed this over the whole area. The lack of lime in the Biwabik formation, Lake Superior, has been explained as follows by Gruner: "There is no reason why calcium and the larger part of magnesium carried to the sea by rivers could not have been deposited in a different, probably a deeper, part of the ocean. The occurrence of almost pure limestone certainly proves that there has been separation of the constituents of river waters" (Gruner, 1922, p. 456). The association of dolomite and ferruginous quartzites has been noticed in other parts of the Mysore State (Balaji Rao, 1922, p. 133).

Source of Iron and Silica.—The identification of true amygdales in the associated Lingadhalli epidiorites (Pichamuthu, 1932, p. 137) proves that these rocks are of the nature of volcanic flows. The occurrence of basic lavas with iron formations has been observed in the Lake Superior as well as in the Gogebic Range (Hotchkiss, 1919, p. 501), Hudson Bay (Leith, 1910, p. 227) and the Belcher Islands (Moore, 1918, pp. 412–38). A similar association has also been noticed in South Africa (Wagner, 1928, p. 20), elsewhere in India (Dunn, 1929; Jones, 1923) as well as in other parts of the world.

Gruner, in discussing the origin of the Biwabik iron formation, has pointed out that the silica might be derived from submarine flows, for, if hot lavas were poured out on the ocean floor, there must have been great chemical reaction and physical disintegration and, though this would not contribute colloidal silica directly to the waters, diatoms and probably other organisms could abstract silica from the detrital material (Murray and Irvine, 1891, p. 248). Gruner, however, favours the hypothesis that iron and silica were derived from land and transported by rivers, for such a source would give a steady supply of material over a long period. Gill has the same explanation for the source of iron and silica in the Gunflint formation (Gill, 1927, pp. 687–728). Moore and Maynard, after a series of experiments, have come to the conclusion that carbonated water is the most effective solvent and that it is able to dissolve sufficient iron and silica from a basic terraine to form a large sedimentary iron deposit (Moore and Maynard, 1929, p. 276).

Conditions necessary for such an origin of the ferruginous quartzites are available in the Bababudans. The prevailing rocks are the basic schists, which would have formed not only the ocean floor but the surrounding land area subject to denudation. Associated with the ironstones are the Lingadhalli epidiorite flows which might have been submarine yielding abundant silica and iron by decomposition and disintegration.

The precipitation of iron and silica is supposed by some to have been caused by the influence of algæ or bacteria. Harder (1919) investigated this problem and came to the conclusion that at the present time, wherever ferric hydroxide was being deposited, it was largely due to the action of iron thread bacteria, but these bacteria have never been found in the sea. Filamentous types of algæ were reported by Gruner (1925, pp. 151–52) in the Soudan cherts of the Vermilion District, Minnesota, but Hawley (1926) produced similar shapes in the laboratory by inorganic processes. It seems, therefore, unnecessary to invoke the influence of organisms, to account for the formation of the banded ferruginous quartzites. According to Zappfe (1931; 1933), the ordinary processes of weathering of rocks can contribute enough iron and silica for the deposition of such strata.

(*e*) Origin of the Banding.

In discussing the origin of banding in the Lake Superior iron formation, Van Hise and Leith state that when ferrous silicate comes into contact with calcium carbonate, ferrous carbonate is precipitated. This precipitate is flocculent, settles slowly and in settling shows a distinct tendency to aggregate into bands separated by varying amounts of free silica. Moore and Maynard formed banded iron and silica by Liesegang's method, but they do not consider that this explanation is applicable to the formation of banded ferruginous quartzite of great thickness. They carried out further experiments to determine whether banding of iron and silica could be brought about by simple sedimentary processes. Freshly precipitated colloidal ferric hydroxide and gelatinous silica in the proportion of three parts of silica to one part of ferric hydroxide, were well agitated in a tall vessel containing sea water and then allowed to settle. In a few hours, they found that the greater portion of the ferric hydroxide, along with considerable silica, settled to the bottom of the vessel. The ferric hydroxide precipitate was of a light reddish brown colour. On examining the vessel several days later, it was seen that this reddish brown layer graded upward into a layer of almost pure white gelatinous silica. This differential settling of a disturbed deposit of gelatinous silica and ferric oxide is considered by them to be important geologically, for in this manner the banding may be instigated, which at a later stage may be considerably enhanced by metamorphism. From experimental results, they suggest that the banding in some of the Pre-Cambrian iron formations could be brought about at the time of their deposition through the differential coagulation of the iron and silica by the electrolytes of the sea. The mutual reaction between oppositely charged particles of iron oxide and silica [illegible] colloidal solution, supplemented by sedimentation, has been considered by Boydell as the cause of banding (Boydell, 1928). The experimental work conducted in the Laboratory of Colloid Chemistry of the Indiana University tends to support Van Hise and Leith, and proves that reactions in a silica gel will produce, under proper conditions, well-defined bands of ferrous carbonate, separated by silica bands (Hartman and Dickey, 1932, p. 1131).

The nature of the banding in the Bababudan ferruginous quartzites has already been described. According to Sampat Iyengar, " the thin quartz layers of the rock are partly secondary enrichment in the schists at the expense of the fibrous cummingtonite". They are " mainly intrusive in character and it is quite probable that a certain amount of *lit-par-lit* injection of the quartz veins in the ferruginous amphibolites and the residual clays might have taken place with the result that a thorough and regular banding of the quartz with the different constituents of the iron ores has been effected by subsequent pressure acting upon the whole mass of the schists " (Sampat Iyengar, 1908, p. 76). The writer considers it extremely improbable that the banding in such a large formation could have developed by the mere *in situ* alteration of a basic schist or by the *lit-par-lit* injection of quartzose material. The layers are not in all cases monomineralic ; there are all stages and gradations and, when some of these bands are examined under the microscope, the individual layers are themselves seen to be composed of more minute stratification. When the Simplon tunnel was excavated through the Alps, a vein of silicic acid soft enough to dig out with the hand was met with (Tyrrell, 1930, p. 221). It is likely that the ironstones were at one time in a similar gelatinous form, and that a reaction analogous to the Liesegang phenomenon took place giving rise to the banding.

7. SUMMARY AND CONCLUSIONS.

This paper contains a detailed study of the geology of the Eastern Bababudans. For the sake of completeness, some of the information already published by the writer in earlier papers has been incorporated. Six new analyses of rocks and minerals occurring in this area are given in this report.

The iron formations rest on epidiorite flows. Intercalated between these, and sometimes associated with the ferruginous quartzites, occur thin beds of argillite which were considered hitherto as aphanitic greenstones. The argillite is hornfelsed near igneous intrusives. Chlorite, talc, tremolite and actinolite schists are interbedded with the banded ferruginous quartzites. The exact mode of origin of these schists is not quite clear and is under investigation, but whether some of them represent igneous intrusives, contemporaneous lava flows or dynamically metamorphosed impure magnesian limestones, the reasons adduced in this paper for considering the banded ferruginous quartzites as sedimentary, remain unaffected. Dykes and sills of quartz dolerite, now epidioritised, traverse the hills and, as a result of their intrusion, amphiboles such as bababudanite are developed at contact in the ferruginous quartzites, and hematite has been converted into magnetite. The felsitic rock from Galipuje and the quartz-tourmaline veins are briefly described.

The ferruginous quartzites occurring in the Mysore State are supposed to be confined to the upper chloritic division of the Dharwars, but the writer considers it probable that these rocks are developed both in the hornblendic and chloritic divisions.

The economically important iron ores, for which the Bababudans is famous, are next described, especially the rich deposits near Kalhatti and Kemmangandi. The iron ores are derived from the banded ferruginous quartzites through the agency of descending surface waters, by the leaching out of the silica and the deposition in its place of oxide of iron or simply by the removal of the silica in solution. In some cases, the bedded ores have accumulated as regular sedimentary bodies and it is suggested that the formation of these ores has taken place during Post-Carboniferous and later periods.

The major portion of the paper is devoted to the study of the banded ferruginous quartzites. These rocks, which exhibit extraordinarily fine bandings of silica and iron oxide, occur as thick beds capping the hills, and forming precipitous slopes on the outer margin of these ranges. Quartz, which is an important constituent, occurs as granoblastic aggregates but sometimes forms layers of fibrous crystals. The physical and optical properties of the soda-amphibole bababudanite are given; the new analysis of this mineral agrees fairly well with the formula

$$4\ NaFe'''\ (SiO_3)_2.\ 2\ FeSiO_3.\ 3\ MgSiO_3.$$

Detailed descriptions, including a chemical analysis, are also given for the non-pleochroic acmite found in this area for the first time by the writer. Asbestos and crocidolite have been recognised, occurring in thin layers associated with the banded ferruginous quartzites.

The thin intercalations of amphibole-magnetite schists were considered hitherto as remnants of basic igneous rocks. The analysis of this schist shows that it bears no resemblance to an igneous rock, but that it is closely related to the similar rocks occurring in the Lake Superior region and which have been considered to be metamorphosed sediments. Like the mineral bababudanite, these amphibole-magnetite schists have also originated as the result of contact metamorphism.

The official opinion in Mysore regarding the origin of the ferruginous quartzites is, that they are metamorphic derivatives of basic igneous rocks. The writer has endeavoured to show in this paper that this view is untenable, and that these rocks are sedimentary in origin. The silica and iron, part of which might be derived from the contemporaneous Lingadhalli flow, have been deposited as chemical precipitates, and the fine banding of the rock has originated by processes similar to the Liesegang phenomenon. Some of the arguments put forward in this paper in favour of the sedimentary origin of the ferruginous quartzites are: the secondary nature of the amphiboles and the amphibole-magnetite schists and the calcium-magnesium ratio in these rocks; the presence of thin beds and intercalations of argillite; the very fine banded nature of the rock; the occurrence of interformational folds; and the indications of the former presence of siderite.

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EXPLANATION OF PLATES.

PLATE I.

FIG. 1. View from Attigundi, of a portion of the Bababudans, showing the characteristic scenery of these hills. The slopes are smooth and grass-covered, while the valleys are thickly forested. The third peak on the left is Mulaingiri, 6,310 feet above sea level and the highest point in the Mysore State.

Fig. 2. Part of the Kemmangandi Iron Mines.

PLATE II.

FIG. 1. Ordinary light. Section of banded ferruginous quartzite. ×10.

FIG. 2. Ordinary light. Section of a portion of an interformational fold. One of the thin laminæ is seen to be broken up. ×10.

FIG. 3. Ordinary light. Section of hornfelsed argillite. The banded nature of the rock is visible. The amphiboles show a decussate arrangement. ×22.

FIG. 4. Ordinary light. Rhombohedral areas in the ferruginous quartzites. They are bordered by iron ore and formed of grains of quartz which are coarser-grained than those in the matrix. These areas probably represent pseudomorphs after siderite. ×10.

PLATE III.

FIG. 1. Ordinary light. Crystals of bababudanite in ferruginous quartzite. The crystals are disposed right across the bands. ×10.

FIG. 2. Ordinary light. Bababudanite-magnetite schist. ×22.

FIG. 3. Ordinary light. Portion of a layer of fibrous bababudanite. ×10.

FIG. 4. Crossed nicols. Section of a band of fibrous quartz. ×22.

PLATE I

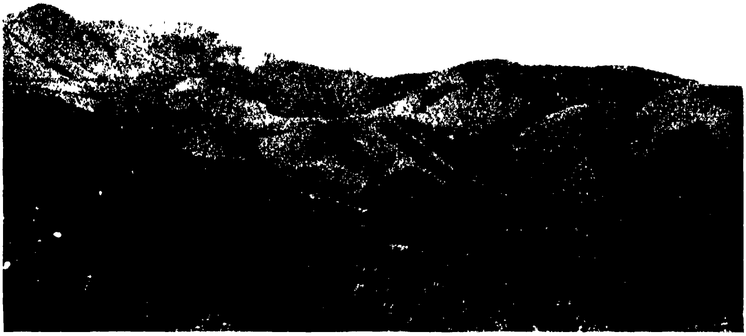

Fig. 1

Fig. 2

Photos: C. S. PICHAMUTHU

PLATE II

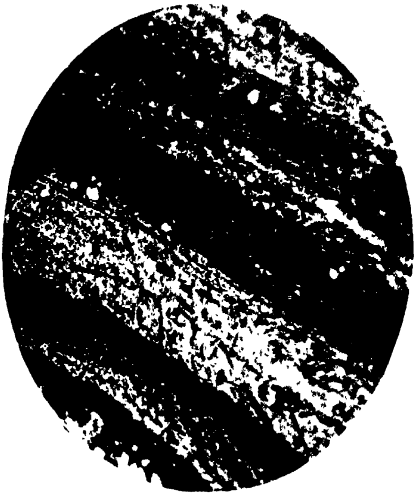

Fig. 1

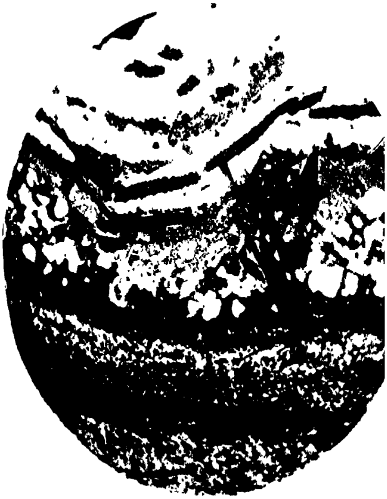

Fig. 2

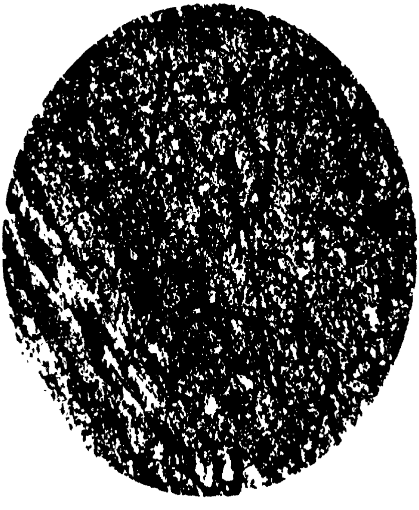

Fig. 3

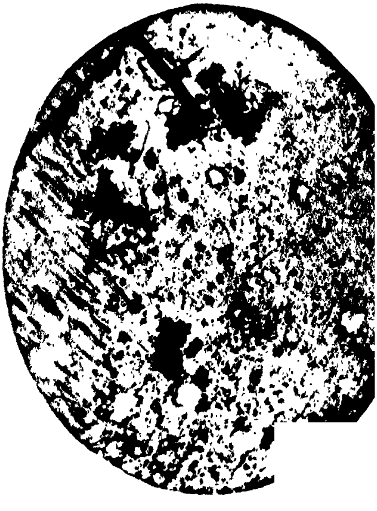

Fig. 4

Photomicros : C. S. PICHAMUTHU.

PLATE III

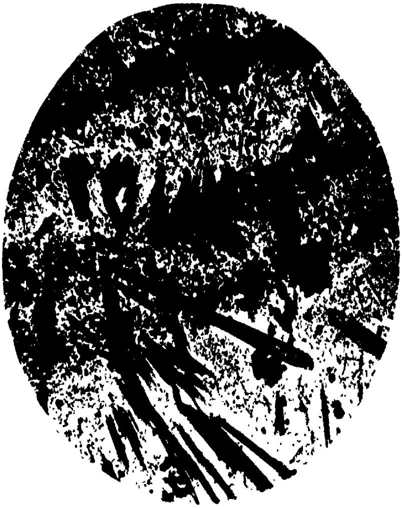

Fig. 1

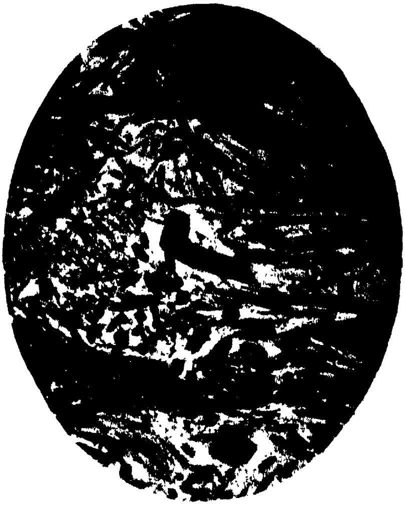

Fig. 2

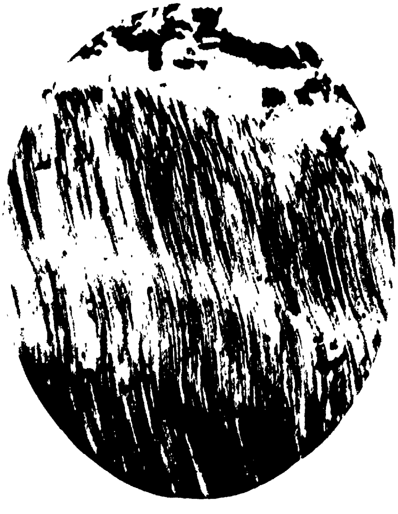

Fig. 3

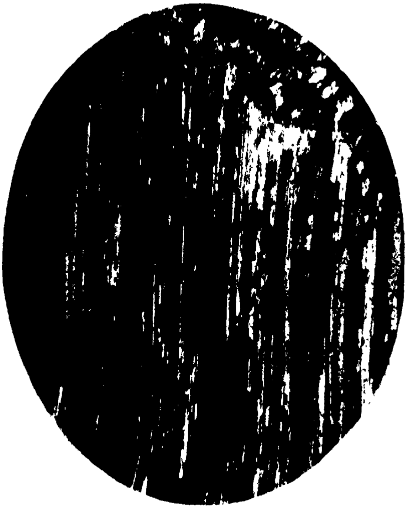

Fig. 4

Photomicros: C. S. PICHAMUTHU.

"APPARENT" AND "TRUE" ADSORPTION FUNCTIONS.*

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PART I. THEORETICAL.

The Ostwald-Bartell Expression for Apparent Adsorption.

In measurements of adsorption in solution by porous adsorbents it is usual to plot $\frac{M(c_1-c_2)}{100G}$ against c_2 where M is the mass of the binary mixture, G is the mass of the adsorbent, c_1 and c_2 the weight per cent. of one of the components in the mixture before and after adsorption, respectively. This function is shown by Williams[1] to represent only apparent adsorption as it differs from true adsorption in not taking into account two factors: (*a*) the adsorption of the solvent and (*b*) the change in mass of the solution consequent on adsorption. In dilute solutions these two factors are of negligible importance and hence apparent adsorption will be equal in magnitude to true adsorption. For the calculation of true adsorption from apparent adsorption, Williams has suggested the measurement of "Total adsorption". Jones and Outridge[2] have pointed out that total adsorption is equal to the product of the average density of the liquid adsorbed and the internal volume of the capillaries of the adsorbent.

Several attempts have been made to explain the apparent adsorption-concentration curve. Ostwald and Izaguirre[3] have observed that true adsorption follows the Freundlich isotherm in dilute solutions. Assuming this to be true for all concentrations they have derived an equation which satisfactorily expresses experimental results. From similar considerations Bartell and Sloan[4] have arrived at the same relation and find it in good agreement with their experimental data. The above workers have all concluded that the apparent adsorption-concentration curve can be interpreted as the result of the superposition of the two Freundlich isotherms corresponding to the true adsorption of each of the components in the binary mixture.

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* Part of the Thesis on "Studies in Adsorption" submitted by K. S. G. Doss in partial fulfilment of the requirements for the Degree of Master of Science of the University of Mysore.

Whether true adsorption can be represented by the Freundlich isotherm may now be considered. Though the inapplicability of the Freundlich isotherm for true adsorption over the whole range of concentration is almost obvious (this term is used in the sense defined by Hardy: "Pure Mathematics"), the following formal proof may be given. The proof consists in showing (*a*) that the two Freundlich isotherms cannot both have an index less than unity, (*b*) that one of the two Freundlich isotherms cannot have an index greater than unity (while the other has an index less than unity), and (*c*) that both the Freundlich isotherms cannot have an index greater than unity.

(*a*) The experimental investigations of Bachmann[5] and Jones and Outridge[2] show that the adsorbates in a porous adsorbent are not subject on the average to any considerable compression. The Ostwald-Bartell expression for total adsorption can therefore be equated to the product of V the internal volume of a gramme of the adsorbent and ρ_g the mean density of the adsorbate. Thus,

$$ac^p + \beta(100-c)^q = V\rho_g$$

where c is the concentration of the first component in the solution in equilibrium with the adsorbent, a and p are the constants of the Freundlich isotherm for the first component and β and q the corresponding constants for the second. Now,

$$\frac{d\rho_g}{dc_g} = \frac{d\rho_g}{dc} \cdot \frac{dc}{dc_g}$$

$$\text{But } \frac{d\rho_g}{dc} = \frac{1}{V}\{apc^{p-1} - \beta q(100-c)^{q-1}\}$$

$$\text{and since } c_g = \frac{100ac^p}{ac^p + \beta(100-c)^q}, \text{ we get,}$$

$$\frac{dc_g}{dc} = \frac{100apc^{p-1}\{ac^p + \beta(100-c)^q\} - 100ac^p\{apc^{p-1} - \beta q(100-c)^{q-1}\}}{[ac^p + \beta(100-c)^q]^2}$$

$$\frac{d\rho_g}{dc_g} = \frac{\frac{1}{V}\{apc^{p-1} - \beta q(100-c)^{q-1}\}\{ac^p + \beta(100-c)^q\}^2}{100apc^{p-1}\{ac^p + \beta(100-c)^q\} - 100ac^p\{apc^{p-1} - \beta q(100-c)^{q-1}\}}$$

$$= \frac{V\rho_g^2\{apc^{p-1} - \beta q(100-c)^{q-1}\}}{100apc^{p-1}\beta(100-c)^q + 100ac^p \cdot \beta q(100-c)^{q-1}}$$

As p and q are both less than unity,

$$\underset{c\to 0}{\mathrm{Lt}}\ \frac{d\rho_g}{dc_g} = \frac{\mathrm{V}apc^{p-1}\rho_g{}^2}{100apc^{p-1}\beta(100-c)^q}$$

$$= \frac{\mathrm{V}\rho_g{}^2}{\beta 100^{q+1}} = \frac{\beta 100^{q-1}}{\mathrm{V}} = \frac{\rho_2}{100},$$

since $\underset{(\text{at } c=0)}{\rho_g} = \rho_2$, the density of the second component.

Similarly $\underset{c\to 100}{\mathrm{Lt}}\ \frac{d\rho_g}{dc_g} = -\frac{\rho_1}{100}$

since $\underset{(\text{at } c=100)}{\rho_g} = \rho_1$, the density of the first component.

But, since the adsorbates are not subject to any considerable compression on the average,

$$\frac{d\rho_g}{dc_g} = \frac{d\rho_{c_g}}{dc_g}$$

where ρ_{c_g} is the density of the binary mixture having percentage of the first component equal to c_g. Thus,

$$\underset{(\text{at } c=0)}{\frac{d\rho_{c_g}}{dc_g}} = \frac{\rho_2}{100};\ \text{and}\ \underset{(\text{at } c=100)}{\frac{d\rho_{c_g}}{dc_g}} = -\frac{\rho_1}{100}$$

[In this proof as well as in the following ones we have considered only the NECESSARY requirements of the density concentration curves, for the Freundlich isotherm to be applicable for expressing true adsorption. The *necessary and sufficient* conditions are bound to be more severe.]

The implications of these conclusions are (i) the density-concentration curves of binary mixtures always have a maximum, (ii) they must have the respective slopes $\frac{\rho_2}{100}$ and $-\frac{\rho_1}{100}$ at $c=0$ and $c=100$. Since these conditions are too severe to be satisfied by the common binary mixtures it may be concluded that both the true adsorption functions of the components of binary mixture cannot follow the Freundlich isotherm in the strictest sense (*i.e.*, with fractional indices).

(*b*) If $p>1$ and $q<1$, as has been employed by Jones and Outridge[2]

$$\underset{c\to 100}{\mathrm{Lt}}\ \frac{d\rho_g}{dc_g} = -\frac{\rho_1}{100}$$

and if $p<1$ and $q>1$,

$$\underset{c\to 0}{\mathrm{Lt}}\ \frac{d\rho_g}{dc_g} = \frac{\rho_2}{100}$$

—conditions which are severe enough by themselves to be ever satisfied by any binary mixture usually met with. Thus, one of the Freundlich isotherms can never have an index greater than unity.

(*c*) The Ostwald-Bartell expression for apparent adsorption (which is deduced on the assumption of the applicability of the Freundlich isotherm for true adsorption) works out to be,

$$S = \frac{ac^p(100 - c) - \beta c(100 - c)^q}{100}$$

Differentiating, we get,

$$\frac{dS}{dc} = \frac{ac^{p-1}(100 - c) - ac^p + \beta qc(100 - c)^{q-1} - \beta(100 - c)^q}{100}$$

If p and q are both greater than unity,

$$\frac{dS}{dc} \text{ is negative both when } c=0 \text{ and when } c=100.$$

This means that there would be a negative adsorption of each component on its low concentration side giving a type of curve theoretically inexplicable and never met with in practice. It may therefore be concluded that *the Freundlich isotherm is inapplicable for representing the true adsorption function over the whole range of concentration.*

This conclusion is amply confirmed by the results of Jones and Outridge[2] as the values of true adsorption calculated from their empirically well-founded equation do not correspond to any Freundlich isotherm. The true adsorption-concentration curves for the system: acetic acid, water, charcoal, are also not of the Freundlich form.[6] It may be pointed out that the amount of adsorption from a pure component as calculated from the Ostwald-Bartell formula differs considerably from the experimental values obtained by Bartell. Furthermore, calculating from the equations obtained by Bartell and his co-workers[7] for the adsorption from four binary mixtures with benzene as a component, the values for the amount of benzene adsorbed from the pure component, instead of being identical, are found to be 4·664, 3·733, 4·808 and 3·491 millimoles per gramme of gel.

Thus the basis of the Ostwald-Bartell expression for apparent adsorption does not seem to be sound.

The Significance of the Apparent Adsorption Function.

In our opinion the so-called "apparent adsorption function" is more fundamental than true adsorption and is of greater significance. B. S. Rao[8] has pointed out the identity of the apparent adsorption function $\frac{M(c_1 - c_2)}{100G}$ with what has been called selectivity $\frac{m(c_g - c_l)}{100G}$ where m denotes the total mass of the adsorbate per gramme of the adsorbent, c_g the weight per cent. of the first component in the liquid in the adsorbent and c_l the weight per cent. in the equilibrium solution. Apparent adsorption or more appropriately "selectivity" represents the number of grammes of one of the components retained in excess in a gramme of adsorbent due to the selective nature of adsorption, assuming that the number of grammes of the mixture adsorbed does not alter as the weight per cent. of the first component in the gel phase alters from c_l to c_g. Similarly the $\frac{\text{“}H\Delta x\text{”}}{m}$ of Bartell and his co-workers[7] works out to be the number of millimoles of the first component retained in excess in a gramme of gel owing to the selective nature of adsorption, the assumption being made that the number of millimoles of the liquid adsorbed does not alter as the mole fraction of the first component in the gel phase alters from x_l to x_g.

It may be noted that the concentrations at which maxima and minima occur in the adsorption isotherms differ according as we plot selectivity or the $\frac{\text{“}H\Delta x\text{”}}{m}$ of Bartell. Identity in physical significance of the two functions can be established only when the simplifying assumptions used in connection with the two functions are eliminated by applying proper corrections. The correction for selectivity can be obtained thus:

$$\text{“Corrected” selectivity} = \frac{mc_g}{100G} - \frac{m'c_g}{100G}$$

where $\frac{m'}{G}$ is the total mass of mixture that would be taken up per gramme of gel if the concentration of the first component in the gel was c_l. So, we can put this equal to

$$\frac{V\rho_g c_g}{100} - \frac{V\rho_l c_l}{100}$$

$$= \frac{V\rho_g(c_g - c_l)}{100} - \frac{Vc_l(\rho_g - \rho_l)}{100}$$

$$= S + \frac{Vc_l(\rho_g - \rho_l)}{100}$$

where S is selectivity (observed) and ρ_g and ρ_l are the mean densities of the adsorbate and the bulk solution respectively.

The correction for $\frac{\text{“}H\Delta x\text{”}}{m}$ of Bartell when similarly worked out gives the relation:

$$\frac{\text{“}H\Delta x\text{”}}{m}\ (\text{corrected}) = \frac{\text{“}H\Delta x\text{”}}{m}\ (\text{observed}) + Vx(\rho_{g_M} - \rho_{l_M})$$

where ρ_{g_M} and ρ_{l_M} are the total number of millimoles present in one c.c. of gel liquid and the equilibrium solution respectively, and x is the mol fraction of the first component in the equilibrium solution.

In calculating the correction factor for S one has to determine ρ_g which can be found out by the method suggested by one of us.[9]

The corrected quantities have the simple relation

$$S\ (\text{corrected}) = \frac{\text{“}H\Delta x\text{”}}{m}\ (\text{corrected}) \times \frac{w_1}{1000}$$

while the uncorrected quantities are related by the equation

$$S = \frac{\text{“}H\Delta x\text{”}}{m} \times \frac{w_1 + \frac{c_l}{100}\left(w_2 - w_1\right)}{1000}$$

where w_1 and w_2 are the molecular weights of the first and second components respectively.

It would be well to point out that applying the above corrections is equivalent to changing the units in which the quantities are expressed. The corrected selectivity is obtained by expressing the concentration in grammes per c.c. and taking into account the volume instead of the weight of the mixture contained in the gel. So also, one can get the corrected $\frac{\text{“}H\Delta x\text{”}}{m}$ by expressing the concentration in millimoles per c.c. and taking into account the volume instead of the number of millimoles of the liquid mixture contained in the gel.

It is of interest to note that the selectivity of B. S. Rao, $\frac{\text{“}H\Delta x\text{”}}{m}$ of Bartell and the corrected selectivity are all measures of Gibbs' adsorption excess. In fact, these quantities are related to the several quantities defined by Guggenheim and Adam[10] in the following manner:

$$\frac{S}{w_1 A} = \Gamma_1^{(M)}\ \text{of Guggenheim and Adam}$$

$$\frac{\frac{\text{“}H\Delta x\text{”}}{m}}{A\times 1000} = \Gamma_1^{(N)}\quad\text{,,}\quad\text{,,}$$

$$\frac{\frac{\text{“}H\Delta x\text{”}}{m}\ \text{corr.}}{A\times 1000} = \frac{S\ \text{cor}}{Aw_1} = \Gamma_1^{(V)}\ \text{of Guggenheim and Adam}$$

where A is the specific surface of the adsorbent.

Calculation of the specific surface of adsorbent from data on selective adsorption.

Of the above-mentioned quantities $\Gamma_1^{(V)}$ is of particular interest since in that case the physical interface is identical with Gibbs' dividing surface. This is related to the concentration of the strongly adsorbed component in the adsorption region thus:

Gibbs' adsorption excess + Bulk concentration × Volume of adsorption region per unit area of interface = Adsorption volume per unit interface × concentration of the strongly adsorbed component in the adsorption region.

Thus $\frac{S_{corr.}}{A} + t\,c' = t\,c'_A$

where t is the thickness of the adsorption layer, c' is the concentration of the first component in the equilibrium solution in grammes per c.c., and c'_A the same in the adsorption layer. In the case of mixtures in which one of the components is much more strongly adsorbed than the other, it may be expected that a sort of saturation may be reached with reference to the strongly adsorbed component. So, it is clear from the above equation that if $S_{corr.}$ is plotted against c' a straight line is obtained, whose intercept on the Y-axis should give the value of $c'_A\ \Lambda\ t$. If σ is the cross-section of the adsorbed molecule (parallel to the adsorbing surface),

$$c'_A = \frac{w_1}{\sigma N t}$$

assuming a complete unimolecular adsorption layer; whence one gets:

$$A = \frac{\text{"intercept"} \times \sigma N}{w_1}$$

Thus the specific surface can be calculated. The value thus obtained is bound to be too low since the adsorption layer even at saturation may not consist of a complete unimolecular layer of molecules of a single type.

The Selectivity-Concentration Curve.

It is evident from the above that the selectivity-concentration curve needs an independent interpretation. There are two types of curves met with in practice, namely, the U-type and the S-type. The general form of the usual U-type curves met with in adsorption studies is of the same form as is obtained by Guggenheim and Adam, for the adsorption at the liquid-vapour interface by the application of Gibbs' equation. The first sudden ascent seems to be due to high rate of accumulation of the preferentially adsorbed molecules with increase in bulk concentration; next the fall begins since the rate of increase of concentration in the adsorption region does not keep pace with increase in bulk concentration. The rectilinear portion of the curve that follows seems to be due to a sort of saturation of the surface by the preferentially adsorbed molecules. The final portion which deviates from rectilinearity is one in which the bulk concentration becomes comparable with the concentration of the preferentially adsorbed component in the adsorption region at the transition point. A quantitative interpretation of the curve seems to be difficult as we have to take into account proximity of adsorbing surfaces and such other factors.

PART II. EXPERIMENTAL.

The theoretical considerations developed in Part I have been applied to adsorption on silica gel from binary mixtures of (*a*) pyridine and water, and (*b*) ethyl alcohol and carbon tetrachloride.

Preparation of Materials and Technique of Adsorption Measurement.

Silica gel.—The silica gel employed was prepared in accordance with the method described in an earlier paper.[11]

Pyridine.—Kahlbaum's pyridine was kept over sodium hydroxide for 72 hours and distilled.

Water.—Conductivity water prepared in the manner described by Acree and Faucet[12] was used.

Carbon tetrachloride.—The Kahlbaum product was purified by standard methods employed in organic chemistry, and finally distilled over phosphorus pentoxide.

Alcohol.—Absolute alcohol finally distilled over barium oxide was used.

In every case the purified substance was treated with silica gel; no appreciable change in the refractive index was observable. The changes in concentration due to adsorption were studied by following up the change in the refractive index by means of a Pulfrich refractometer using sodium light.

For carrying out the adsorption a weighed amount of gel was kept in contact with a weighed amount of the mixture in a stoppered "serum" bottle. Often preliminary cooling of the mixture was necessary to minimise the volatilisation due to the rise in temperature during adsorption. The results obtained are tabulated below :—

TABLE I.

Adsorption on Silica gel from Pyridine-Water Mixtures.

C_l ..	91·66	91·40	80·00	79·92	67·67	58·47	56·2	44·77
$10^3 \times S_{obs.}$ ..	−14·4	−14·9	−3·5	−2·3	15·7	35·2	41·5	41·4
$10^3 \times S_{corr.}$ ..	−14·2	−14·7	−3·5	−2·2	15·8	35·3	41.6	66·4
$w_1 \times \frac{\text{"}H\Delta x\text{"}}{m}$ ..	−49·2	−50·7	−9·1	−6·0	33·0	64·2	73·1	102

C_l ..	41·40	30·93	12·20	11·46	9·08	3·77
$10^3 \times S_{obs.}$ ..	76·4	108	138	139	138	91·8
$10^3 \times S_{corr.}$ ..	76·5	108	139	139	138	91·8
$w_1 \times \frac{\text{"}H\Delta x\text{"}}{m}$ ..	112	142	152	153	148	94·2

TABLE II.

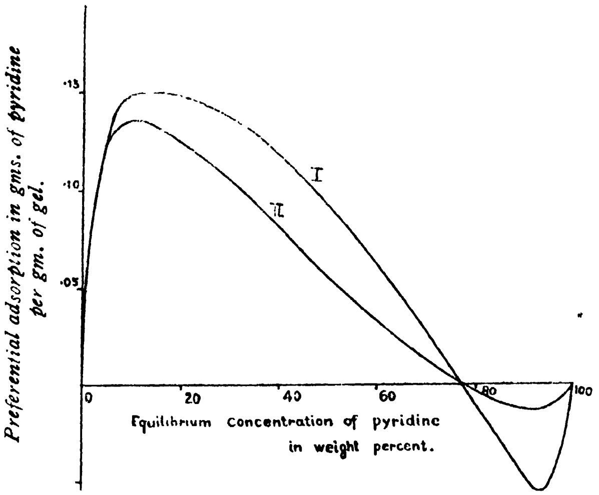
Adsorption on Silica gel from Carbon tetrachloride-Alcohol Mixtures.

$C_l \times 100$ ..	0·0	1·6	5·0	13·2	24·0	35·2	49·0	58·5
C_l .	0·0	1·0	3·3	9·0	17·6	31·2	44·2	57·6
$10^3 \times S_{obs.}$ ..	91·6	122	184	189	170	128	100	76
$10^3 \times S_{corr.}$ ..	91·6	111	179	176	146	98	68	47
$w_1 \times \frac{\text{"}H\Delta x\text{"}}{m}$ ..	91·6	119	171	157	120	74	49	33

DISCUSSION.

The results show that the corrected selectivity for carbon tetrachloride-alcohol mixtures is different from either of the two other quantities, *viz.*, "selectivity" and $\frac{\text{"}H\Delta x\text{"}}{m}$. Since pyridine and water have comparable specific volumes, their binary mixtures give for $S_{obs.}$ and $S_{corr.}$ practically identical values; on the other hand, the Bartell expression, $\frac{\text{"}H\Delta x\text{"}}{m}$, needs a large correction. (See Figs. 1 and 2.)

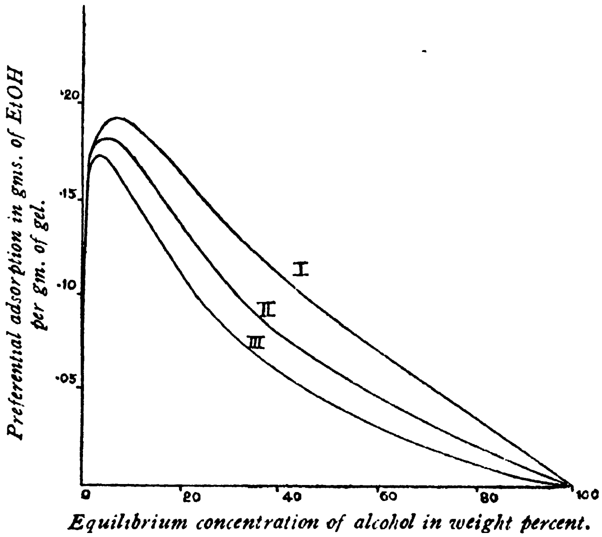
There is a considerable difference of opinion as regards the type of curve characteristic of "Apparent adsorption".



Curve I. Bartell's $\frac{\text{"}H \Delta x\text{"}}{m} \times \frac{w}{1000}$.

Curve II. Selectivity (obs.) and Selectivity (corr.).

FIG. 1. Adsorption on silica gel from pyridine-water mixtures.



Curve I. Bartell's $\frac{\text{"}H \Delta x\text{"}}{m} \times \frac{w}{1000}$.

Curve II. Selectivity (corrected).

Curve III. Selectivity (observed).

FIG. 2. Adsorption on silica gel from carbon tetrachloride-alcohol mixtures.

Bartell and co-workers have tried to show[13] that S-type is really the general form. They have an S-type curve with *n*-butyl alcohol-benzene-silica system as well as with ethyl alcohol-benzene-silica system. But Jones and Outridge[2] have obtained a U-type curve for the first-named system and one of us (B. S. Rao[8]) for the latter. We have repeated the experiments and confirmed the earlier work of B. S. Rao. No negative adsorption of ethyl alcohol on silica gel could be obtained from benzene-ethyl alcohol mixtures, while Bartell has obtained a negative adsorption of alcohol with an equilibrium mixture having 90% benzene. Our results show an actual positive adsorption of alcohol at the same equilibrium concentration.

Calculation of the Specific Surface of Gel.

It has already been shown that the specific surface

$$A = \frac{\text{"intercept"} \times \sigma N}{w_1}$$

From data on CCl_4—EtOH mixtures, we get "intercept" = 0·21 (see Fig. 3); $N = 6{\cdot}06 \times 10^{23}$; $w_1 = 46$; $\sigma = 20{\cdot}5 \times 10^{-16}$ calculated from work on films on water.

$\therefore A = 6 \times 10^6$ sq. cms. per gramme, a value of the right order of magnitude.[14] In the above calculation the influence of capillaries is neglected; it is to be pointed out that in every one of the existing methods for estimating the specific surface this factor has been neglected.

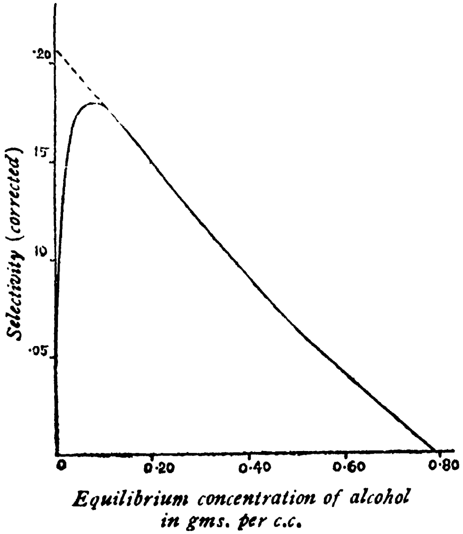


FIG. 3. Adsorption on silica gel from carbon tetrachloride-alcohol mixtures..

Factors underlying Selective Adsorption.

Freundlich[15] has suggested that the adsorption of a solute increases as the surface tension of the solvent increases. Patrick and Jones[16] suggest that the order of increase of adsorption of a solute from a series of solvents is the same as the order of decrease of the solubilities of the solute in the solvents. But these two suggestions (apart from their being defective in other ways) cannot be of general application since they do not take into account the specific influence of the adsorbing surface. Bartell and his co-workers suggest[13] that the adhesion tension is the deciding criterion. But Bartell's value[14] for the adhesion tension of acetone is lower than that for water. Thus, in the case of adsorption by silica gel from acetone-water mixtures, Bartell's criterion would lead him to expect a weaker adsorption of acetone whereas the opposite has been observed by one of us (B. S. Rao[8]). B. S. Rao has suggested that, in the case of silica gel the surface can be approximately looked upon as a water surface. Thus the adsorption of a solute would be determined by the interfacial tension of the solute against water. But this criterion cannot be applied to the case of completely miscible liquids.

The factors which seem to be of importance in determining the nature of selective adsorption in binary mixtures are (i) The individual avidities of the two components of the binary mixture towards the adsorbing surface, and (ii) The avidity of the two components for each other. Bartell's adhesion tension rule considers only the former aspect while the criterion laid down by Patrick and Jones takes into account only the latter. We are of opinion that for a correct interpretation of adsorption data, both the factors must be considered. In the carbon tetrachloride-alcohol-silica gel system, there is no marked avidity between carbon tetrachloride and ethyl alcohol, and the silica surface has a stronger avidity for the polar alcohol than for the non-polar carbon tetrachloride. This accounts for the U-type curve obtained for this system.

On the other hand, pyridine and water are known to have great avidity for each other. In fact, hydrates of pyridine are known. In such a case it may be expected that there should be a tendency for the preferential adsorption of a complex of a particular composition. The complex preferentially adsorbed has the composition of the liquid giving zero selectivity and this in the case of pyridine-water mixtures consists of 80% pyridine which practically corresponds to the monohydrate. Similarly the liquid giving zero selectivity for acetone-water mixtures has 75·5% acetone closely corresponding to the complex $CH_3.CO.CH_3$, H_2O. This appears to be very significant and is suggestive of the formation of molecular compounds between the liquid components at the adsorbing surface. Whether the S-type curve is in all cases associated with the formation of molecular compounds at the adsorbing surface is being investigated in this laboratory.

SUMMARY.

1. The assumptions underlying the derivation of Ostwald-Bartell expression for "apparent adsorption" are shown to be unsound.

2. "Apparent adsorption" is shown to be a measure of Gibbs' adsorption excess and is thus more significant than "true adsorption".

3. The nature of the two typical "S" and "U" shaped adsorption curves obtained with pyridine-water and alcohol-carbon tetrachloride mixtures has been discussed.

4. The specific surface of silica gel has been calculated by a new method involving data on selective adsorption.

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MIXED POLAR THEOREMS ON PLANE CUBICS.

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§ 1. INTRODUCTION.

I have recently given[1] a mixed polar theorem relating to the pencil of four tangents that can be drawn to a non-singular plane cubic from a point on the curve itself. In the course of the investigations leading on to this theorem, I have been able to derive a number of other subsidiary theorems dealing with mixed polars and poloconics which, although not directly connected with the mixed polar theorem, have an intrinsic interest. These theorems have been given in §2 of this paper. Further theorems which follow from a direct application of the mixed polar property with the aid of pure geometric and symbolic methods have next been given in §3. It is shown in this section that some of the theorems given by Rey. J. Pastor[2] are immediate geometrical consequences of the mixed polar theorem.

§ 2. THEOREMS ON POLO-CONICS AND MIXED POLARS.

Theorem 1.—*The mixed polar of any two points* P, Q *in the plane is the polar w.r.t. the poloconic of* PQ *of the point of intersection of the polar lines of* P *and* Q.

Let the cubic be $a_x^3 \equiv b_x^3 = 0$ and the points P and Q be y and z and the line PQ, $u = 0$. The poloconic of PQ is given by

$$\ominus = (abu)^2\, a_x b_x = 0$$

which can also be written as

$$\ominus = \theta_x^2 \phi_u^2 = 0 \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

Let the polar lines of P and Q meet at the point t. The polar of this point *w.r.t.* (1) is given by

$$\theta_x \theta_t \phi_u^2 = 0.$$

We have also the relations

$$a_t a_y^2 = 0 = a_t a_z^2 \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (2)$$

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[1] *Proc. Ind. Acad. Sci.*, Vol. 1, No. 6, (1934), p. 367.

[2] *Atti. Accad. naz. Lincei*, Rend, VI, S. 20 (1934), pp. 459–62,

Operating with $\left(a\frac{\partial}{\partial\theta}\right)\left(b\frac{\partial}{\partial\theta}\right)\left((ab)\frac{\partial}{\partial\phi}\right)^2$ on $\theta_x\theta_t\phi_u^2$

we get $(abu)^2\,(a_xb_t + b_xa_t) = 0$

which is equivalent to

$$(a_yb_z - a_zb_y)^2\,(a_xb_t + b_xa_t) = 0$$

since y and z are points on $u=0$. Expanding the left-hand side of this last equation and using (2) we derive

$$a_ya_zb_yb_z\,(a_xb_t + b_xa_t) = 0$$

and remembering that a and b are equivalent symbols this gives

$$(a_xa_ya_z)\,(b_tb_yb_z) = 0$$

i.e., the equation required is $a_xa_ya_z = 0$ which is the mixed polar of P and Q.

COR.—*The mixed polar of* P, Q *touches the poloconic of* PQ *if* P *coincides with* Q *at a point of the cubic.*

Let the mixed polar of P, Q meet $u=0$ at R ; the points P, Q, R then form a degenerate apolar triangle of the cubic. The polar lines of P, Q, R form a triangle circumscribed to the poloconic and the three lines joining these points of contact are the mixed polars of the three pairs P, Q ; Q, R and R, P. Hence we have

THEOREM 2.—*The triangle formed by the mixed polars by pairs of three collinear points forming a degenerate apolar triangle is inscribed in the poloconic of the line.*

The above theorems are very much simplified and can be made to yield further interesting results when P and Q are on the cubic itself. The point R will then be the third intersection of the line PQ ($u=0$) with the cubic and Theorem 2 transforms itself into

THEOREM 3.—*The triangle formed by the mixed polars by pairs of the three points of intersection of a cubic by a line is inscribed in the poloconic of the line.*

As a simple corollary we can deduce the condition in order that the mixed polar of P, Q may be the tangent to the cubic at R. This is obviously true if P, Q and R coincide in which case the mixed polar becomes the inflexional tangent. An alternative case arises when the poloconic of the line PQR degenerates into a pair of st. lines, for, the point of intersection of the polar lines of P and Q will be the double point of this degenerate poloconic and by Theorem 1, the mixed polar of P, Q coincides with the line joining this double point to R, *i.e.*, the tangent at R. Hence the

COR.—*The mixed polar of* P *and* Q *is the tangent at* R *either when* P, Q, R *coincide or when the line* PQR *has a degenerate* *poloconic. In the latter case the mixed polar of any of the three pairs is the tangent at the residual point.*

We can now proceed further and investigate how the mixed polars of the three pairs of points are related to the points P′, Q′, R′ which are the other intersections with $u=0$ of the polar conics of P, Q, R respectively. Referring to the adjoining diagram[3], let the tangents at P, Q, R to the cubic form the

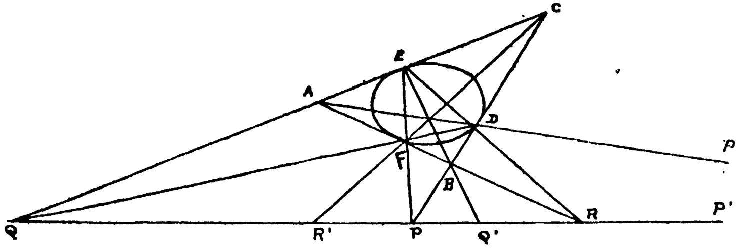

FIG. 1.

triangle ABC which is circumscribed to the poloconic of $u=0$. If D, E, F are the points of contact of these tangents with the poloconic it follows by Theorem 3 that DE, EF, FD pass through R, P, Q respectively and are the mixed polars of P, Q ; Q, R and R, P. The mixed polar of Q, P passes through R or in other words, the polar of Q *w.r.t.* the polar conic of P passes through R, which means that Q and R are conjugate points for the polar conic of P, *i.e.*, (PP′, QR) is a harmonic range. The points P′, Q′, R′ therefore determine the cubic covariant of the binary cubic form given by P, Q, R, the Hessian covariant being the intersections of u with the poloconic of u. Hence using Clebsch's principle of translation the points P′, Q′, R′ are given as the intersections of u with the curve

$$Q=(abu)^2(cau)c_x^2\ b_x=0.$$

But from a property of this curve[4] the points P, P′ ; Q, Q′ and R, R′ are conjugate points relative to the poloconic of u. *Therefore* AD, BE, CF *pass through* P′, Q′ *and* R′ *respectively.* Consider further the polar of E *w.r.t.* the polar conic of Q. Since the polar of R *w.r.t.* this conic, *i.e.*, the mixed polar of Q, R is PE, it follows that the polar of E *w.r.t.* the same conic passes through R. EQ being the tangent at Q to the cubic is also the tangent at Q to the polar conic of Q. Hence the polar of E *w.r.t.* this conic passes through Q, *i.e.*, is the line QR or QQ′ showing that EQ′ is tangent at Q′ to the polar conic of Q. This gives us

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[3] This diagram is the same as given in Salmon, H.P.C. (3rd Edition), p. 157.

[4] See Clebsch, Lindemann and Benoist, *Leçons*, t. 2 (1880), p. 279.

THEOREM 4.—*If a line* u *meets a cubic in* P, Q, R *the vertices of the triangle formed by the mixed polars by pairs of these three points are the poles of* u *w.r.t. the polar conics of* P, Q, R.

An application of the well-known theorem[5] that the polar conic of a point x is harmonically inscribed to the poloconic of a line u when x lies on u, gives a further interesting result. As mentioned above, P, P′ are conjugate points w.r.t. the poloconic of u and hence the point of intersection of the polars of P, P′ w.r.t. the same conic forms with P, P′ a self-conjugate triangle for the poloconic. From the above theorem of Clebsch this must be a triangle inscribed in the polar conic of P and P, P′ being points on this polar conic, the third vertex of this triangle should also lie on it. Hence the

THEOREM 5.—*The polars of* P, P′, Q, Q′ *and* R, R′ *w.r.t. the poloconic of* u *meet on the polar conics of* P, Q *and* R *respectively.*

§ 3. THEOREMS ON SALMON PENCILS.

I call the pencil of four tangents that can be drawn from a point P on a cubic to the curve itself as the "Salmon pencil of P" and shall proceed to deduce some theorems relating to Salmon pencils by the use of the mixed polar theorem referred to in §1 which can be stated as follows :—

MIXED POLAR THEOREM.—*The polar line of any point* P_1 *in the plane w.r.t. the Salmon pencil of a point* R *on the cubic is the same as the mixed polar of the points* P *and* Q *in which the line* P_1R *meets the cubic again.*

If the points P and Q coincide at P_1 the point R will be the tangential of P and the mixed polar of P, Q becomes the line PR itself and hence passes through P_1. Given the point P_1 there are however six points like R, *viz.*, the tangentials of the points of contact of tangents from P_1 to the cubic, or the intersections of the cubic with the *satellite conic* of P_1. Hence we have

THEOREM 6.—*The polar lines of any point in the plane w.r.t. the Salmon pencils of the six points of intersection of the cubic with the satellite conic of the given point are concurrent at the given point itself.*

If the point P_1 be on the cubic itself the polar line of P_1 *w.r.t.* the Salmon pencil of any point R on the cubic is the same as the mixed polar of P_1 and the point P which is the third point of intersection of P_1 R with the cubic. As a particular case let P_1 be a point of inflexion on the cubic ; the mixed polar of P_1 and P is the same as the polar of P w.r.t. the polar conic of P_1 which now degenerates into the inflexion tangent at P_1 and the harmonic polar. Hence the mixed polar passes through the intersection of these lines and this gives *Rey Pastor's first theorem. The polar lines of an inflexion point* P_1 *of* C^3 *w.r.t. the Salmon pencils of points on* C^3 *all pass through a fixed point which is the intersection of the inflexional tangent at* P_1 *and the harmonic polar of* P_1.

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[5] Clebsch, Lindemann and Benoist, *ibid.*, p. 287.

If P_1 be any fixed point of the curve other than a point of inflexion we can consider the problem of finding the envelope of the polar lines of P_1 w.r.t. the Salmon pencils of the points on C^3. By the mixed polar theorem this reduces to the envelope of the mixed polars of P_1 and the different points on the cubic. If P_1 be denoted by y and any point on the cubic by ξ, the envelope mentioned is the envelope of the line

$$a_x a_y a_\xi = 0$$

with the condition $a_\xi = 0$

and hence is in general a curve of the third class. Hence we have

THEOREM 7.—*The envelope of the polar lines of a given point on* C^3 *with respect to the Salmon pencils of the different points on the cubic is in general a curve of the third class.*

I hope to return in a further paper to an investigation of the properties of this class cubic.

Let us now consider two given points P_2 and P_1 in the plane and determine the points on C_3 such that the polar lines of P_1 w.r.t. the Salmon pencils of these points are all concurrent at P_2. Let P_1 and P_2 be denoted by y and z and any point on the cubic by ξ. The Salmon pencil of ξ is represented by the quartic

$$p_x{}^4 = 4a_x{}^3 b_\xi{}^2 b_x - 3a_x{}^2 a_\xi b_x{}^2 b_\xi = 0 \quad .. \quad .. \quad (3)$$

and the polar line of y w.r.t. (3) can be found to be

$$a_y{}^3 b_x b_\xi{}^2 + 3a_y{}^2 a_x b_y b_\xi{}^2 - 3a_x a_y b_y{}^2 a_\xi b_\xi = 0 \quad .. \quad (4)$$

If this passes through ξ we have

$$a_y{}^3 b_z b_\xi{}^2 + 3a_y{}^2 a_z b_y b_\xi{}^2 - 3a_z a_y b_y{}^2 a_\xi b_\xi = 0 \quad .. \quad (5)$$

which shows that the required points are the intersections of the cubic with the conic

$$a_y{}^3 b_z b_x{}^2 + 3a_y{}^2 a_z b_y b_x{}^2 - 3a_z a_y b_y{}^2 a_x b_x = 0 \quad .. \quad (6)$$

Hence the number of points sought for is six and we can state

THEOREM 8.—*Given two points* P_1 *and* P_2 *in the plane, there are six points on* C^3 *such that the polar lines of* P_1 *w.r.t, Salmon pencils of these six points all concur at* P_2.

Reserving for a future occasion an investigation of the nature of the conic given by (6), I proceed to consider some particular cases. Let P_1 lie on the cubic or $a_y^3 = 0$. In this case (6) reduces to

$$a_y^2 a_z b_y b_x^2 - a_z a_y a_x b_y^2 b_x = 0 \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

which is of the form

$$\lambda C_y - P_{yz} P_y = 0$$

C_y being the polar conic of y, P_y the polar line of y and P_{yz} the mixed polar of y and z. Thus (7) passes through the intersections of C_y and P_y, *i.e.*, it touches the cubic at y. This gives

THEOREM 9.—*There are four points on the cubic such that the polar lines of a point* y *on the curve w.r.t. the Salmon pencils of these four points concur at a point* z.

Specialising still further let us choose z such that $a_y^2 a_z = 0$ in addition to $a_y^3 = 0$. This means that z lies on the tangent at y. We might therefore take z to be the tangential of y. In this case (7) still further reduces to

$$(a_x a_y a_z)\,(b_y^2 b_x) = 0$$

$$i.e., \qquad P_{yz} P_y = 0$$

P_y meets the cubic in P_1. P_1 and P_{yz} being mixed polar of P_1 and its tangential P_2 also passes through P_1. Hence the six points of intersection of the conic (6) with C^3 reduce to P_1, P_1, P_1, P_2 and two other points P_1', P_2''. The polar lines of P_1 w.r.t. Salmon pencils of P_1', P_1'' pass through P_2. Using the mixed polar theorem these polar lines are the mixed polars of P_1, P_1' and P_1, P_1''. Hence the

THEOREM 10.—*If* P_1 *be a point on the cubic and* P_2 *its tangential and if the mixed polar of* P_1, P_2 *meets the cubic in* P, P_1', P_1'', *the mixed polars of* P_1, P_1' *and* P_1, P_1'' *meet at* P_2.

Another special case of a different nature can be obtained by recalling the corollary to Theorem 3. Let P, Q, R be three collinear points on a cubic such that the poloconic of PQR degenerates into a pair of st. lines through P_2. By a well-known theorem P_2 is on the Hessian and PQR is a tangent to the Cayleyan. The corollary referred to shows that the tangents at P, Q, R to the cubic pass through P_2. If P′, Q′, R′ be the points of contact of the other three tangents from P_2 to the cubic, P′, Q′, R′ also lie on a line and the polar conic of P_2 is the pair of st. lines PQR, P′Q′R′ meet at P_1 which is also on the Hessian and is the conjugate pole of P_2. Hence by corollary to Theorem 3, the polar lines of P_1 w.r.t. the Salmon pencils of these six points P, Q, R, P′, Q′, R′ all concur at P_2. This gives *Rey Pastor's second theorem. To every point* P_1 *of the Hessian there correspond six Salmon pencils such that the* *polar lines of* P_1 *w.r.t. these pencils are concurrent at* P_2 *the Steinerian conjugate of* P_1.

This is also immediately evident from equation (6). For, if y and z be conjugate poles on the Hessian we have

$$a_y{}^2a_z = 0$$

since polar conic of z passes through y and the equation $a_xa_ya_z=0$ identically satisfied, *i.e.*,

$$\left.\begin{array}{l} a_ya_za_1 = 0 \\ a_ya_za_2 = 0 \\ a_ya_za_3 = 0 \end{array}\right\}$$

Hence equation (6) reduces to

$$b_x{}^2\, b_z = 0$$

which is the polar conic of $P_2(z)$ which immediately proves the above theorem.

TIPU'S COMMERCIAL POLICY.

BY M. H. GOPAL.

"Tippoo prohibited," writes a later contemporary of his,[1] "the importation of any foreign commodities so that the Canara merchants carried specie always out and thus the country so far as Arcot was drained of its gold." This appears to be a misinterpretation of the Sultan's policy. For instead of prohibiting *all* foreign trade, Tipu prohibited trade with hostile countries only.

Hardly one year after the Second Mysore War, the Sultan objected in one of his letters to the exportation of rice to Pondicherry.[2] This may lead to the supposition that intercourse was prohibited even with friends. But the true reason appears to be that as the route to Pondicherry lay through the Carnatic, any export of goods to the French settlement would naturally lead to commerce with the Company's territories. Rather than run this risk, Tipu sent specie from his kingdom to purchase the goods. This suggests, as Kirkpatrick observes, that the Sultan's ideas were exactly the opposite of the bullionist notion of precious metals. In another letter written a year later[3] Tipu refers to the prohibition of the sale of rice to the merchants from the English and Portuguese ports. In February 1787[4] the people of Calicut were forbidden to trade with the Company. This aspect of Tipu's trade policy, *viz.*, the prohibition of intercourse with his enemies, is stated by the Marquis Wellesley thus[5]: "Hitherto, all traffic between your subjects and dependents and those of the late Sultan was nearly prohibited, by the restraint to which his hatred of the British nation or his ignorance and prejudice had subjected the communication with your possessions." But this policy was not new, for, according to an European traveller of the middle of the 18th century,[6] it was the practice of the Indian princes to settle their disputes with the Europeans by laying a general interdict on the trade and dealings of their subjects with them.

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[1] Journal of the Mysore Campaign from Hyderabad to Seringapatam (*British Museum Additional MSS.*, Vol. 13663 f. 19).

[2] Tipu to Raja Ram Chander, 9th April 1785 (William Kirkpatrick: *Select Letters of Tipu Sultan*, No. XIX).

[3] Tipu to the Imam of Muscat, 16th Jan. 1786 (*Ibid.*, No. CCVII).

[4] Tipu to Urshud Baig Khan Foryda of Calicut, 2nd Feb. 1787 (*Ibid.*, No. CCCCXXXII).

[5] Governor-General to the Court of Directors, 3rd Aug. 1799, para 72. This policy is definitely enunciated in Art. 99 of Tipu's Revenue Regulations (Vide *British India Analysed*, Part I).

The prohibition applied only to his enemy territories. An English contemporary of Tipu writes,[7] "At a subsequent period he would appear to have acquired juster notions of what was essential to the prosperity of his country, having, in the year 1794, issued some commercial regulations, tending to encourage a limited trade with his neighbours." This does great injustice to the Sultan. For he seems to have had better aquaintance with commerce than Kirkpatrick credits him with, and his encouragement of trade began *pari passu* his prohibition of it with enemies, although the commercial regulations were issued some years later.

This question can be studied from two points of view—the attitude towards foreign merchants and the trade activities of the Government. Almost since the peace of 1784 Tipu spared no pains to increase foreign trade. In a letter dated 28th June 1785 to Shaikh Ahmed, a merchant,[8] he promises to give him all kinds of aid. "On your arrival here you shall in all things experience our care and protection agreeably to your wishes, and be appointed in charge of the mercantile concerns, etc. A proper place shall be assigned to you for a factory, and such advances of money be made to you as may be requisite for enabling you to carry on your trade (advantageously), all the profits of which shall rest with you for the term of two years, during which time also we promise to grant you exemption from all duties on your merchandise." No Government could offer better facilities and greater concessions than Tipu does in this letter. As Kirkpatrick himself recognises,[9] this indicates how much the Sultan had it at heart to open up trade with those countries of which he had no jealousy. The same policy continued throughout his reign. In November 1785 the Sultan wrote to some Armenian (Khoja?) merchants[10] welcoming them to trade with Mysore and promising to give them every facility, provided they first sold some articles to him at a reasonable price. In January 1786 Tipu issued a general order " to the actual and future Aumils of our ports,"[11] that he had remitted two-fifths of the duties payable by a certain merchant. Likewise other letters mention similar remissions as regards others.[12] In another letter[13] Tipu says, "Do you, therefore (because duties are remitted) continue constantly to send your ships and *dows* laden with merchandise to our parts." In his instructions of March 1796 to his ambassadors to Zeman Shah, the sovereign orders them to assure the merchants of Cutch, "that the dealers in wares and horses who may bring them for sale to the ports of the Khodadad Sircar will be exempted from duty, and that the duties on other articles also which they may bring for sale will be taken off."[14]

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[6] Grose, *East Indies*, Vol. I, p. 248.

[7] Kirkpatrick, *op. cit.*, p. 33.

[8] *Ibid.*, No. LXXVI.

[9] *Ibid.*, page 104.

[10] Tipu to Khajeh Seth and other merchants, 26th Nov. 1785 (Kirkpatrick, *op. cit.*, No. CLXIII).

The Sultan's efforts to promote trade were not restricted to countries near by. His letter to the Raja of Pegu dated 22nd January 1786[15] mentions the despatch of two persons to open "a commercial intercourse between the two states [Mysore and Pegu] whereby an exchange of the commodities of each may be established to the mutual convenience and advantage of both," and invites the Raja to mention what articles he needs from Mysore. That this deputation was actually sent is very probable since in a letter of 31st March 1786[16] the Sultan asks two of his officers to get ready for sailing. Even to far off China[17] the friendly hand was extended, and as the Chinese merchants appear to have been afraid of piracy in the Indian Ocean, Tipu desired to send men-of-war for their protection.[18] As mentioned already Tipu encouraged trade with Muscat, a port near the entrance to the Persian Gulf, which is even to-day a very important commercial centre. He even established his own trading depots there.[18a]

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[11] Tipu to the Amils of ports in general, 16th Jan. 1786 (*Ibid.*, No. CCIV). Also see Tipu to Mao Seth, Dalal of Muscat, 16th Jan. 1786 (*Ibid.*, No. CCVI).

[12] *E.g.*, Tipu's orders to the Amils of the port of Kurial or Mangalore and Tipu to the Imam of Muscat, 16th January 1786 (Kirkpatrick, *op. cit.*, Nos. CCV and CCVII).

[13] *Ibid.*

[14] Instructions to Mir Habibulla and Mir Mohamed Reza. [Wood: *Review of the origin etc. of the Decisive War with Tipu Sultan*, Appendix (A), No. 21.]

[15] Kirkpatrick, *op. cit.*, No. CCXI.

[16] See Kirkpatrick's observations on the foregoing letter.

[17] Kirkpatrick, *op. cit.*, Appendix p. xxxvii. Regulations 6-9.

[18] *Ibid.*

[18a] *Vide* Tipu's instructions to Mir Mohamed Baquir and others about leading a "commercial expedition" [Wood: *op. cit.*, No. 11]. Also see the narrative of the proceedings of the Mysore ambassadors to Mauritius [*Ibid.*, No. 18] about depots in foreign territories; also see letter from the representatives of Mauritius to Tipu Sultan [*Ibid*, Appendix(B), No. 7], and Tipu to Gulam Ali Khan [Kirkpatrick, *op. cit.*, No. CCCCXIII].

The advantages offered to foreign merchants are put in a nutshell by the Sultan himself in a letter to some Armenian (Khoja ?) merchants.[19] " The duties upon (such) goods (as you may import into our dominions) are without exception (hereby) remitted. Bring, therefore, with entire confidence to our ports, and into our kingdom either by sea or land (as you may think proper) your silk stuffs and (other) merchandise and there (freely) buy and sell. Wheresoever you may (choose to) bring your goods, there a place shall be assigned for your residence ; and if you should at any time be in want of workmen or labourers, the same shall be furnished you on hire by our Taalukdars." The first concession, thus, was the remission of the whole or a part of the duty to be paid at the port. What this duty was is not certain. This was perhaps not the specific anchorage duty, at the established rate of 40 rupees per *dingy* (or vessel) in the port of Calicut,[20] since this was on vessels and not goods and was in the nature of harbour toll and the exemption from which was an additional concession sometimes given. Probably the impost exempted from was the *ad valorem* tax of 10 per cent. levied on the goods of all merchants. Kirkpatrick observes[21] that it is not known whether this duty was on imports alone or on exports also. But that it was on both imports and exports is suggested by the Sultan's reference[22] to "the duties levied in our ports from time immemorial on all goods to be bought and sold". Whether there were other duties also is not known. The next aid accorded to trade was the supply of accommodation to merchants,[23] and of sites for the erection of trading centres or *kothies*.[24] Loans were given to enable the traders to carry on their business,[25] and when they needed, the state procured for them on hire artisans and workmen.[26] And profits were exempted from taxation for limited periods.[27]

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[19] *Kowlnama* to Yakub and other merchants, 11th Jan. 1787 (Kirkpatrick, *op. cit.*, No. CCCCXXV).

[20] Tipu to the Amils of Calicut and Tipu to Mao Seth, Dalal of Muscat, both dated 16th Jan. 1786 (*Ibid.*, No. CCVI).

[21] *Ibid.*, p. 240.

[22] Tipu to the Amils of ports in general, 16th Jan. 1786 (Kirkpatrick, *op. cit.*, CCIV.) Duties on imports are mentioned in Tipu's letter No. CCCCXXV quoted above.

[23] *Kowlnama* to Yakub and other merchants, 11th Jan. 1787, quoted above.

[24] *Kowlnama* to Shaikh Ahmed, 27th June 1785 (Kirkpatrick, *op. cit.*, LXXVI).

[25] *Ibid.*

[26] Tipu's letter No. CCCCXV, *loc. cit.*

[27] *Kowlnama* to Shaikh Ahmed, *loc. cit.*

It is, however, doubtful if all these concessions were given to all traders. These were perhaps the maximum terms. Some merchants were exempted from a certain percentage of the duties. For instance Mao Saith, Dalal of Muscat, paid only 6%, as the customs duty,[28] while the Imam of Muscat paid only 5%.[29] But both were exempted for the anchorage duty. Advances of money were not probably given to some. These concessions appear to have been differingly granted to different merchants. The motives determining these terms are not known. It may be conjectured that the longer the distance from which the trader came, the greater was the concession.[30] Secondly, the political importance of the country or the person may have had a great influence.[31] Again the trade concessions offered to the Mysoreans, as in the case of Muscat, may have determined the terms to some extent.[32] Lastly, it is not impossible that the religion of the trader influenced the offer.

These advantages were in a sense limited. They did not apply to all commodities. For the Khodadad Sircar itself monopolised the trade in some articles which constituted the chief commercial resources of Mysore,[33] *e.g.*, sandalwood, betel-nut, pepper and cardamoms. Further some merchants, for instance, the Armenians (Khojas ?), were forced to sell first some articles to Tipu at a reasonable price, as the condition of the concessions.[34] How this " reasonable " price was determined is not known. But this insistence, however reasonable the price, was really a clog on the advantages. Kirkpatrick remarks[35] "the Sultan however exported rice to Muscat in his own vessels and imported the commodities of that country into Mysore, but he also obliged the Muscat merchants to purchase all the Government rice on hand at a price probably fixed by himself before he allowed them to buy elsewhere." This restraint is perhaps exaggerated. First there does not appear to have been any monopoly of rice by the Government.[36] As regards the Government competition in trade, it was a legitimate one and, moreover, it appears to have traded like any other private merchant, for example paying the usual duties.[37]

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[28] Tipu to the Amils of ports in general, 16th Jan. 1786; also Tipu to Mao Seth, Dalal of Muscat, 16th Jan. 1786, *loc. cit.*

[29] *Ibid.*

[30] Tipu to Mao Seth, *loc. cit.* The Sultan allowed 4% remission to Mao Seth and 5% to the Imam of Muscat.

[31] *Ibid.*

[32] *Ibid.*

[33] Macleod's Memorandum on the Commerce of Mysore, 12th July 1799 (*Asiatic Annual Register*, 1798-99, p. 306). Also Kirkpatrick's observations on Tipu's letter No. CCVI.

[34] Tipu to Khaje Seth and others, 26th Nov. 1785 (Kirkpatrick, *op. cit.*, No. CLXIII). Regarding the government rates of purchase *cf.* Article 59 of Tipu's Revenue Regulations (*op. cit.*).

[35] Kirkpatrick, *op. cit.*, p. 240.

A word might be said about inland duties. Transit duties, which were until quite modern times a common and often greatly revenue yielding item of taxation, were to be found in Mysore also. Macleod writes in July 1799[38] " It would greatly encourage trade if the road duties on all articles were abolished throughout the Mysore territories," and adds, "It would moreover be of importance to the Company's possessions and manufactures if all duties on raw cotton and thread were discontinued throughout the Rajah's country, as it is in the Company's dominions." There were perhaps numerous transit duties and tolls in addition to local taxes.[39] For example Buchanan mentions[40] a tax on the exportation of cloth from the town of Valuru : " each bullock load of cloth (cotton) pays a duty of one Sultany fanam or a little more than eight pence." He further observes that raw cotton brought from Hoskote paid a small duty on every bullock load that enters Valuru, while at Hoskote it paid heavier duties. A curious fact about these duties is noticed by Buchanan[41] "Far from considering the customs exacted at different places on the road as a burden, the traders consider them as advantageous ; for the customhouse is bound to pay for all goods that may be stolen or seized by robbers, within their respective districts. This seems to be an excellent regulation which seems to be in general use throughout the peninsula." The duties were thus in the nature of an insurance premium for the goods.

We shall now consider the commercial and industrial activities of the state. The Khodadad Sircar was a great trader and one of the articles of importance was sandalwood. Buchanan states[42] in 1800 that no person was allowed to cut sandalwood without the permission of the Amildar or the officer who sold it on Government account. Sandalwood like black pepper and cardamoms was the monopoly of the state,[43] Mysore producing sandalwood and the west coast pepper and cardamoms. Since Haider's days the sale of these goods was a business of the Government. Tipu writes[44] "The first sort of sandalwood you must sell at the rate of 120 pagodas the candy; the second sort at 100 pagodas; the third sort at 90 pagodas, the fourth sort at 80 pagodas the candy. You must not sell them at any other (*i.e.*, at less) prices than these." In other letters[45] the Sultan orders the articles to be held back till the prices rise. In Haider's days these commodities were sold principally to the Company, but under Tipu they appear to have secured wider markets. Writing one year after Tipu's fall, Buchanan observes[46] "I found there [in Heggadadevanakote] a Portuguese agent of the Commercial Resident at Mangalore who had been employed to collect a purchase of this article that had been made by the Government of Bombay from the Dewan of Mysore," and adds[47] "There chips and fragments, with the smallest assortment of billets, answer best for the Arabian market; and from them the essential oil is distilled. The largest billets are sent to China, and the middle-sized billets are used in India." It will be seen how these markets were studied by Tipu when he launched his scheme to establish "factories" or commercial depots from Arabia to China.[47a]

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[36] Tipu's commercial regulations—Marine forces, No. 7 (*Ibid.*, Appendix page xxxvii).

[37] *Ibid.*, No. 5.

[38] Macleod's Memorandum, *op. cit.*

[39] These will be discussed in another paper.

[40] Francis Buchanan, *Journey from Madras through the Countries of Mysore*, etc., Vol. I, p. 40.

[41] *Ibid.*, Vol. III, p. 332.

[42] *Ibid.*, Vol. I, p. 51. Elsewhere (Vol. II. p. 138) the traveller observes that the regulations forbidding the cutting of sandalwood by private persons were not enforced with rigour in Tipu's reign.

Two more branches of state enterprise were silk and pearl fishery. Kirkpatrick writes[48] "The Sultan's anxiety to establish a pearl fishery on the coast of Malabar, as well as to introduce the culture of the silkworm into his dominions appears to have been considerable; but I believe he failed entirely in both." "It may be inferred," adds Kirkpatrick,[49] "from the silence of the subsequent correspondence on the subject, either that the requisite divers were not procurable, or that the attempt, if actually made, did not succeed." It is strange that Kirkpatrick should remark that the subsequent correspondence is silent on the point since in April 1786 Tipu refers again to pearl divers and in September 1786 to silkworms and actually sent two of his officials to Bengal to procure them.[49a] And according to Kirkpatrick himself[49b] he either actually established or proposed to establish twenty-one principal stations within his dominions for breeding silkworms. It is not known how far these attempts were successful. At the present day in Channapatna, an important silk centre in Mysore, the Mussalmans have successfully taken up this industry, and how far this is due to Tipu's efforts cannot be determined.

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[43] Tipu to Mir Kasim, 25th Nov. 1785 (Kirkpatrick, *op. cit.*, No. CLX)· Also Articles 22-24 of Tipu's Revenue Regulations (*op. cit.*)

[44] Same to same, 9th Dec. 1785 (*Ibid.*, No. CLXXII).

[45] Same to same, 25th Nov. 1785 and 12th Jan. 1786 (*Ibid.*, Nos. CLX and CC).

[46] Buchanan, *op. cit.*, Vol. II, p. 132.

[47] *Ibid.*, p. 134.

[47a] *Vide* the description of the Mysore commercial expedition to sell pepper, in Tipu's Instructions to Mir Mohamed Baquir and others [Wood: *op. cit.*, No. 11]. Also Tipu to Mohamed Esa, 24th November 1786 [Kirkpatrick *op. cit.*, No. CCCCIII].

[48] Kirkpatrick, *op. cit.*, p. 187. Also see Tipu to Mir Kasim, 17th Nov. 1785, 25th Nov. 1785 and 12th Jan. 1786 (Kirkpatrick, *op. cit.*, Nos. CLX, CLIX and CC).

[49] *Op. cit.*, p. 234.

The Khodadad Sirkar also competed with private people both in retail and wholesale trade, foreign as well as indigenous. To increase foreign trade, commercial treaties were concluded with foreign powers and *kothics* or trading centres were established in foreign lands. One of Tipu's letters to Mir Kasim[50] refers to a depot in Muscat at the entrance to the Persian Gulf; and this depot was placed under the charge of the amil of Mangalore. From the instructions to the Mysore ambassadors to Zeman Shah of Persia, we learn that there was a depot already existing at the port of Mundra in the peninsula of Cutch. The Sultan sued for a commercial alliance between Mysore and Cutch and desired to establish a new factory at Mindy in the same kingdom. The embassy was also to go to Karachi and request for permission to erect a depot there paying the established duties of that kingdom. The Sultan's ambassadors to Constantinople in 1785[51] were to request the port of Basara or at least the permission to erect a factory. As early as 1785 there was a depot in Jeddah.[52] After the war of 1792 Tipu attempted to establish *kothies* in the territories of the Company, the Mahrattas, the Nizam and others and issued a wise and comprehensive code of regulations.[52a] As it is uncertain how far these were actually put into practice, the code may be studied separately. Here however it may be noted that the distribution of the trade centres, as evident from the adjoining map, proves that the Sultan showed a great deal of commercial wisdom. In his own kingdom he

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[49a] Tipu to Mir Kasim, 24th April 1786 [Kirkpatrick, *op, cit.*, No. CCLVIII also same to same (*Ibid.*, No. CCLXXII)]; Tipu to Syed Mohamed, 27th Sept. 1786 (*Ibid.*, No. CCCLXXV).

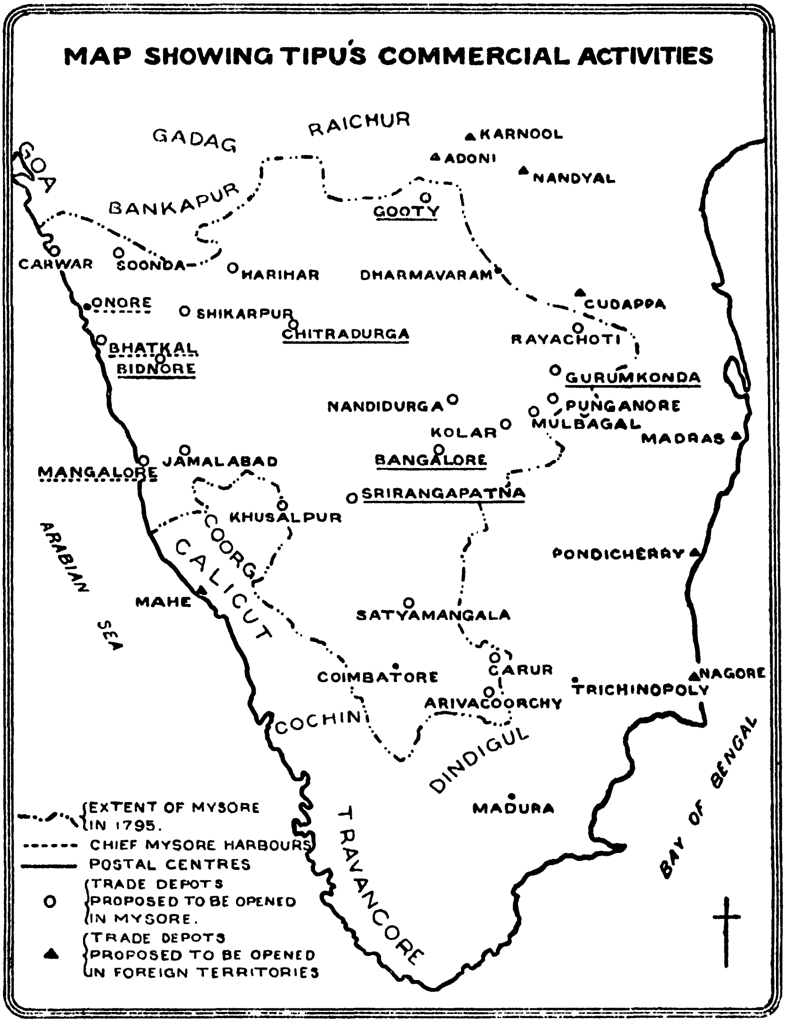
[49b] *Op. cit.*. p. 419.

[50] Dated 12th Jan. 1786 (Kirkpatrick, *op. cit.*, No. CC). Also same to same, 24th April 1786 (*Ibid.*, No. CCLVIII).

[51] Tipu to Ghulam Ali Khan and others, 1st March 1786 (*Ibid.*, No. CCXXXIV).

[52] Tipu to Mir Kasim, 25th Nov. 1785 (*Ibid.*, No. CLX).

[52a] These were different from the Revenue Regulations which will be discussed in a separate paper.


MAP SHOWING TIPU'S COMMERCIAL ACTIVITIES

Drawn by—D. N. M. R.

opened three important ports—Mangalore, Karwar and Bhatkal. The first two are even now important commercial centres, specially for coastal trade. The value of Bhatkal can be judged from the fact that the present-day Mysore State contemplated the acquisition of the port for opening up its foreign trade. To facilitate its trade activities the Khodadad State kept its own ships. In 1786[53] the Sultan refers to buying and lading rocksalt on his own ships. In the same letter he refers to the shipwrights at Muscat as excellent at building *dows* and *dingies*, and in another letter[54] asks for the despatch of 10 shipwrights, and 100 *calashies* at 7 rupees a month.

As regards internal and retail trade, Tipu as early as 1785 established trading centres all over the country. In reply to a letter from Raja Ramchander,[55] one of his officers, the Sultan quotes the Raja's own words, "that in conformity with our orders, you have established shops on our behalf in every Taluk (under your authority) and engaged in our service, a *surrof* and accountant for conducting the affairs of each." The Sultan had his own warehouses in Seringapatam where the goods were sold by the Amildars.[56] Such establishments were perhaps common all over the country.[57] Thus the retail trade also was engrossed. And the commercial regulations issued in the years 1793 and 1794 aimed perhaps, at least so far as the internal trade was concerned, at a better organisation and unified system of control. It may even be that some more district centres of distribution were established.

We may pause to consider how this system worked and what its results were. The main purpose of these warehouses appears to have been to make them distributing centres so as to help the local traders to vend goods in villages and interior parts. For Raja Ramchander says[58] that the richer traders alarmed at the establishment of the government warehouses migrated to other places, while Tipu adds[59] "They (*i.e.*, the traders) will finally come and make their purchases at our warehouses." But retail sale to the ultimate consumer was also undertaken in centres where the warehouses were established and especially in the capital and other important places.[60]

These objects do not seem to have been realised. At any rate at the inauguration of the scheme about 1785, this enterprise spelt failure both to the state and to the subjects. One of Tipu's officers writes,[61] " In some districts the object of profit is completely frustrated ; while in others, the gains are so very small as to be inadequate to the monthly pay of the *surrofs* and accountants, owing (as you say) to the more considerable towns, where, heretofore, gold and silver bullion and specie to the amount of thousands of pagodas, used to be brought for the purposes of traffic, being now forsaken by the traders, who taking alarm at the establishment of our shops (or warehouses) resort, in consequence, to other places : none but the poorer classes, in short, ever dealing with them, then only to the amount, perhaps of six or seven *fanams*." Thus the traders, for whose convenience primarily and as whose competitor secondarily the shops were opened, boycotted them. Only those who were too poor to emigrate were forced to buy from these shops. As to why it should have been so if the consumer bought from them is uncertain. Tipu observes[62] " Admitting that the profits, for instance, are only seven pagodas and the expense on account of the wages of the *surrof* and accountants, amount to ten, how long can this last or the dealers continue to carry their money and bullion to other places ? They will finally come and make their purchases at our warehouses."

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[53] Same to same, 24th April 1786, *loc. cit.* *Vide* the commercial embassy referred to by Tipu (Wood : *op. cit.*, No. 11).

[54] Same to same, 6th May 1786, *loc. cit.* Also see same to same, 12th January 1786 [Kirkpatrick, *op. cit.*, No. CC).

[55] Dated 2nd Aug. 1785 (Kirkpatrick, *op. cit.*, XCVIII).

[56] Buchanan, *op. cit.*, Vol. I, p. 69.

[57] Letter No. XCVIII quoted above.

[58] *Ibid.*

[59] *Ibid.*

[60] Buchanan, *op. cit.*, Vol. I, p. 69.

The failure of these shops so far as the consumers were concerned may be attributed to another cause. It appears[63] that at Seringapatam the goods were sold much above their real value, which was done by forcing a share of them upon every man in proportion to his supposed wealth. This was one of the sources of oppression, peculation and defalcation of revenue. " The friends of the Amildars were excused from taking a large share of the goods, while the remainder were forced upon poor wretches, whose whole means, when torn from them, were inadequate to the estimated value of the goods ; and the outstanding balances are always large."[63a] As the prices at the warehouses were thus higher than those prevailing in the market, the traders naturally boycotted them, because the state may have forced them not to import goods directly but to buy them from its own depots. The policy of the Government in thus forcing upon poor people its unsold goods, naturally resulted in the ruin of its subjects, and their poverty led to financial loss to the state itself.

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[61] Tipu to Raja Ram Chander, *loc. cit.*

[62] *Ibid.*

[63] Buchanan, *op. cit.*, Vol. I, p. 69

[63a] *Ibid.*

We may now consider briefly the commercial regulations referred to before. These regulations[64] to increase the commercial prosperity of the Khodadad State, were issued by the Sultan at two different periods—on 25th March 1793 and on 2nd April 1794. The principal object of these regulations appears to have been the encouragement of the seaborne trade, although inland commerce was not neglected. The commercial department was called the *Mulikut Tujar*, under a Board of Trade consisting of 9 officers.[65] The object of this department was to attract, by concessions and encouragements, foreign merchants to Mysore, to control the supply of commercial imports and exports, like silks, sandalwood, etc., and to supervise and be in charge of the state factories at home and abroad. Every proceeding was to receive the sanction of the Sultan and thus the sovereign was at the bottom of every transaction. To ensure agreement in the board the officers were to be as far as possible *syeds*.

The detailed directions for the department of trade may be reviewed under the following heads[66] :—

(1) The marine force,
(2) The factories or *kothies* at Muscat and Cutch,
(3) Commercial capital,
(4) Depots in Mysore.
(5) Commercial deposits or banking,
(6) Miscellaneous regulations.

The marine regulations will be discussed in greater detail while dealing with the navy ; but it may be noted here that at first about 1793 the marine forces were under the Board of Trade, though later on an independent admiralty department was created under the name of *Mir Yum*. However a hundred ships were, according to these regulations, required to be built as quickly as possible from the labour and material available near the dockyards. These ships appear to have been men of war. The merchants of Jamalabad (*i.e.*, Mangalore), Majidabad and Wajidabad were to build 31 commercial vessels, in return for which they could lade them with articles like rice and cocoanuts, not reserved for the exclusive trade of the state. No other vessel was to be used. Trade with China was to be fostered by sending Mysore goods to that country and by giving armed protection to Chinese ships.[67] As regards the factories at Muscat and Cutch, there were two at each place. One in each port was under the Board of Trade, the others under the Asofs of Jamalabad and Wajidabad. The articles traded in were pepper, sandalwood, cardamoms, etc., and were probably sources of great profit.

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[64] These regulations are printed in Kirkpatrick, *op. cit.*, Appendix E. The Roman letters in the following footnotes refer to the page in the Appendix while the Arabic ones refer to the number of the regulations.

[65] Kirkpatrick, *op. cit.*, Appendix p. xxxiv.

[66] *Ibid.*, p. xxxvi.

Regarding the capital for trade, the regulations run thus: "The sum of four lakhs of *rahities* (*i.e.*, Kantiroy pagodas) has been committed to you in trust for commercial purposes. With this money you are to make the necessary purchases of gold and silver bullion, cloths, elephants, etc., and to hold the same in readiness (for exportation). With the blessing (or aid) of God the most high, countless profit shall be thereby acquired." All goods purchased even by the sovereign or the State from the Government depots were paid for. The goods were sold by the Asofs or Government Officers. Pledges of bullion and other valuables were received for the payment of the purchase money at $1\frac{1}{8}$ of the money due. The Government goods imported and exported were not exempt from the duties. "You are to pay," writes the Sultan,[68] "the established duties and imposts on all articles in the same manner as is done by the ryots in general."

For the sale of articles, depots were established all over the kingdom in thirty centres,[69] while a kind of minor depots was established in other places and left under the care of agents who were to be changed annually. The accounts and appointments were to be sanctioned directly by the Sultan himself. The other regulations relating to these depots deal with their inspection and control. The location of these centres in different parts of the Mysore territories is noteworthy. They were distributed all over the State, though they were few in the centre and the south-west. The guiding principle was mainly commercial, and perhaps partly political as well. The south-western side from Coimbatore almost up to Mangalore, with the exception of Khusalnagar, is bereft of any centres because that part of the country is mountainous. In the coast there were five centres very close to one another perhaps because trade in this part was brisk.

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[67] *Ibid.*, p. xxxvii, 6-9.

[68] *Ibid.*, p xl, 5.

[69] *Ibid.*, p. xli, 2. The following were the thirty centres :— Seringapatna. Sulamabad (Satyamangala), Vazimangala (Arivacochy), Bangalore, Bagalur, Kolar, Mulbagal, Madanapalli, Zufarabad (Gurmuconda), Punganur, Rachonty, Fyze Hisar (Gooty), Dharmawar, Farmkhat-Hisar (Chitradurga), Nagara (Bidnur), Shikarpur, Surdah, Mangalore, Khusalpur or Khusalnagar, Barkur, Carwar, Jamalabad, Bhatkal, Futahabad, Karwar, Gussup or Kurmp (?), Banavasi, Gurdoon Shakh (Nandidoorg), Bay-Nazyer (Harihar).

Tipu even thought of establishing depots in foreign territories for purposes of commerce.[70] These centres were to buy rare goods and send them to Mysore for sale, and also sell rarities of Mysore in the foreign market. Including the two existing depots at Cutch and Muscat were to be 17 in number. The situation of these depots also was determined by commercial wisdom. The Sultan's purpose in establishing the trade depots can best be expressed in his own words :[71] " Sending in charge of your deputies or agents to other countries, the produce of our dominions, and disposing of the same there : the produce of those countries must be brought hither in return, and sold at such prices as will afford (good) profit." Tipu desired not only the State to enjoy the benefits of trade but wanted his subjects to share them. He therefore invited his subjects to invest their money in the State enterprises. The heads of the depots were authorised to receive deposits or investments of any sum above five rupees up to five hundred rupees, the return on the investment or " profit " was 50% of the sum invested, 25% from 500 to 5,000 and 12% above 5,000.[72] The deposit could be withdrawn at any time and a profit in proportion to the period of deposit was also paid. The heirs of a deceased depositor had the same rights as the deceased.

The so-called profit was in fact interest, but as Tipu was a strict Mussalman, who could not take or give interest as such, he termed it profit. The curious procedure of lowering the interest for larger sums might be regarded as indicating that the Sultan tried his best to encourage, according to his own ideas, the small capitalist to invest his money. But this probably had a retarding effect on investments. For unless a person had surplus money which he could invest nowhere-else at a greater advantage, it was not to his benefit to invest more than 500 or 5,000 rupees. Thus the real incentive to investment of larger sums was wanting. In other words " the extraordinary difference in the rates of interest assigned, respectively, by this regulation, to the small and great, is at utter variance with the principles which usually govern public loans" in modern countries. Tipu perhaps adopted this plan in pursuance of the object to help the feeble. the helpless and the destitute which forms the preamble to these regulations. Major Wilks[73] however thinks that these regulations were "a project for enticing his subjects into a swindling loan," a project which "was too glaring to be misunderstood, although covered with the thin cloak of religion." However the regulations indicate that the Sultan was a bad businessman. The interest allowed to the first two classes is so high that it is doubtful if, in the ordinary course of trade, he could have realised profits enough to pay the interest without selling goods at abnormal prices.

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[70] *Ibid.*, p. xliii, 3. The following were the centres :—
Karnoul, Madras, Pondichery, Poona, Cudappa, Nagore (in Tanjore), Wyrag (depending on Poona), Pagarkote (belonging to Rao Rasta), Utuce (belonging to Rao Rasta), Maligong (depending on Hyderabad), Hunmabad (depending on Hyderabad), Nandiar (? Nundyal) (depending on Hyderabad), Rachore (Adoni ; Raichoor), Muscat, Karachi of Sind, Mahe-to France.

[71] *Ibid.*, p. xliv, 7.

[72] "That whosoever shall deposit, with you any sum from five to five hundred Imaumies (*i.e.* rupees) for the purpose of being employed in traffic (on his account), such person shall be entitled to receive (from you) at the end of a year, together with the principal amount of the said deposit, a profit or increase, of half an Imaumy on every Imaumy deposited or advanced " etc.

The miscellaneous regulations relate to the encouragement to be given to the cultivation of sandalwood and black pepper, the State purchasing the products from the ryot.[74] With the exception of some articles reserved for trade by the State, the employees of the commercial department could deal with other articles on private account and were generally exempted from paying taxes.[75]

These regulations were promulgated about 5 to 6 years before the death of the Sultan. It is therefore probable that at least some of them were not acted upon in the interval before 1799.

Another enterprise which was quasi-commercial was the iron-foundry and arms manufactory at Kankanhalli.[76] This industry appears to have been conducted on Government account and for its exclusive benefit. But all articles bought by the State or the Sultan were actually paid for, although they were produced in the State factory. "A similar practice, however, seems to have prevailed in other departments of the Government; and the object of it might possibly have been to preserve the accounts of the proceeds on profits of the monopolies in question as distinctly as possible."[77]

It is not possible to estimate how far the industrial and commercial activities of the State were a drag or a help to the finances of the State, and what the financial consequences of the policy were.

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[73] *History of Mysore*, Vol. II, p. 269.

[74] Kirkpatrick, *op. cit.*, p. xlvi, 1.

[75] *Ibid.*, 2 and 3.

[76] Tipu to Zynal Abideen, 6th Nov. 1786 (*Ibid.*, No. CCCXCIV) Also Tipu to Raja Ram Chander, 13th June 1786 [*Ibid.*, No. CCXCIV]; and Article 78 of Tipu's Revenue Regulations (*op. cit.*).

[77] *Ibid.*, p. 441.

THE PANIPAT BHAKAR.

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Among the contemporary accounts of the Third Battle of Panipat, the version of Kasi Raja Pandit is the most familiar one. As Kasi Raja was a servant of the Nawab of Oudh, his account, while forming an important source, cannot present a true and correct statement of all the facts. Hence an "inside view" of the fateful days of the Panipat would prove an invaluable aid in our just appreciation of the whole catastrophe. We owe it to the indefatigable enthusiasm of the late R. B. K. N. Sane, B.A., that we are offered a Maratha view of the War. This *Panipat Bhakar* edited by Mr. Sane years ago, was composed by one Raghunatn Yadhav, a Chitnis of the family, just two years after the bloody events. It was based on the diaries kept by two leading citizens of Benares. The narrative was undertaken by the command of the most unfortunate of women, Gopikabai, the wife of the third Peshwa.

The Bhakar of Yadhav Narayana opens with the story of the transfer of power into the hands of the Peshwas by the saintly king Sahu and proceeds to state how the banner of the Marathas was carried up to the walls of Attock by the daring energy of Raghunatha Rao and Chimaji Appa. When the whole of the Hindustan was brought under Maratha sway, Balaji Baji Rao (1740–61) desired to depute Sadasiva Rao Bhao to consolidate the conquests in the North. On this one Purandare remonstrated with the Peshwa that the Bhao was quite indispensable at the Court of Poona and that his precious life should not be endangered in distant expeditions. But the mind of the Peshwa was made up and he was determined to fling back the Durrani incursions into Hindustan. So orders were issued to all the Chiefs of the Maratha confederacy to march into the Panjab in support of their generalissimo. This army of expedition was composed of 350,000 horse, 60,000 infantry and 1,200 pieces of artillery under Ibrahim Khan Garadi. Having chastised the Nizam at Udgir 1760 A.D. for presuming to intercept them, the Maratha troops forced their way without further let or hindrance and reached the outskirts of Delhi in a great spirit of elation.

The Rajputs, as is well known, stood by, refusing to cooperate with the Marathas, whereas the Rohillas and the

Nawab Shuja Mahammed Dowla of Oudh welcomed eagerly the invader, Ahmad Shah Abdali. On this Sadasiva Rao reminded the Nawab of their former friendship and invited him to join the Marathas against their common enemy and to exact vengeance for his frequent incursions into India which resulted in the weakening of the Delhi Empire and the consequent disorders in the North. Shuja Mahammed Dowla retorted that the debacle of the Delhi Empire was mainly the work of the Marathas and the Jats and no compromise was possible with such enemies. That Jats who were till now friendly to the Marathas, suddenly turned hostile and took to " trimming " with both the sides. Thus Sadasiva Rao found himself opposed by the Rajputs, the Jats and the Muslim Chiefs of the North.

Betrayed on every side, the Maratha leader grimly resolved on fighting for India single-handed, and ordered his army to entrench themselves on the path of the invader. As the Durrani Chief attempted to cross the river Jumna he met with stout resistance from his opponents' heavy artillery and the undaunted Muslim allies swore to die rather than retreat and ultimately succeeded in crossing the river in spite of heavy odds. After this first encounter both sides gradually marched up to Panipat where they contented themselves in playing a waiting game within their own dug-outs rather than trust their fortunes to the arbitrament of war.

Those three months of inactivity, merely marked by irregular skirmishing, told on the Maratha camp. They were cornered and their supplies were cut off by their enemies. Famine stared them in the face. Then the Maratha leader resolved on forcing an issue with the enemy. Having divided his troops into three main divisions, the Bhao led them against the opponents. The battle raged furiously from the early morning to the setting of the sun. Severe losses were inflicted on the enemies and then the Peshwa's hosts retired to their encampments in high spirits.

The intervening truce was utilised by the Durrani and his allies to send an embassy to the Marathas charging them with ingratitude and rebellion against their lawful suzerains of Delhi, demanding them to surrender all their territories north of the River Narmada and offering them in return, three crores of rupees to cover their expenses of war. Sadasiva Rao replied that the Marathas were the sole guardians of Hindustan and the Chatrapati of Satara was the real Emperor of India, and that Ahmad Shah Abdali was but an interloper who should shift his forces to the other side of the Indus within twenty-four hours.

Having despatched this spirited message to the invader, Sadasiva Rao called together a Council of War in which the assembled leaders plighted their word to defend their Chief and their Empire to the last drop of their blood. So the next day after these negotiations saw the third encounter between the forces of the Hindus of Deccan and the Muslim Chiefs of the North. Both sides fought with great valour and grim determination. The Maratha cries of "Jai Sahu Maharaj" and "Har, Har, Mahadev" mingled with "Ya Allah Khuda," "Ya Rahiman Rahim" rent the air. The earth was strewn with its thousands of dead. Many were the wounded and they were groaning with pain. In this gory battle, the Maratha leader got down from his horse and fell upon the enemies with swords in both hands. At the end of the day, both the parties withdrew to their respective shelters for rest and recuperation.

The morning after the battle was devoted to the search for the wounded and dead. Under orders of the Bhao, the last rites to the dead, on his side, were gone through with meticulous care and the wounded were attended to in person and cheered up with presents and praises.

On the same day, the Afghan invader advised his friends to make their peace with the Marathas, since the latter seemed invincible and accordingly an envoy of peace was despatched to the Maratha camp. But the Maratha leader would not entertain any idea of compromise until the country was rid of the last invader.

The Marathas declined the proffered peace, in spite of their distressing conditions, which would have daunted a less stout heart than that of the Bhao. Famine stalked in their camp. Cut off from the outside world by the general hostility of the surrounding population, the Maratha leader sent a foraging expedition, which merely ended in the complete annihilation of the party under Govind Pant Bundela. His head was severed by the enemies and thrown into the Maratha camp as a lesson and a portent. But Sadasiva Rao soon recovered from this unexpected shock and determined on delivering a smashing blow to his antagonists though his own followers were exhausted and starving for the last three days.

The sufferings of the Maratha warriors became intense and agonising; and they begged their beloved leader to withdraw and avoid complete destruction of the Maratha forces. But the general Bhao could not believe that his men could be defeated by any power on earth. He still hoped to crush the enemy as never to rise again. At any cost, the honour of the Chatrapati must be kept untarnished.

Soon after, Sadasiva Rao called together his personal friends and leaders and advised them to go home safe to Poona along with Viswas Rao, the darling of his parents. As for himself, death was sweeter than the disgrace of a retreat. But the young son of the Peshwa, a youth of eighteen, would not retrace his steps from the path of glory and honour so well blazoned by the immortal achievements of his forbears. Death is the end of every life in this world. But what a death, he wished, it would be for him to embrace in that field of Kurukshetra so much hallowed by the Epic fights of the Kuru Race, Abhimanyu and Arjuna.

Thus both tne uncle and the nephew resolved not to be outdone by each other in the maintenance of their family honour. They rigorously abstained from food for the whole day. The dawn of the next day saw them issue the order for final assault on the enemies. Seating themselves on three powerful elephants, they led a murderous charge into the very valley of death. At about noon, the enemy was decisively beaten and showed signs of wavering. The Marathas were within an ace of victory. The Durrani Chief, being a man of foresight, suddenly poured into the melee his reserve of 50,000 horse and charged down the tired and famished troops of the Peshwa. Viswas Rao was killed by a bullet; and for once the great fortitude of Sadasiva Rao deserted him. He resolved on following his nephew to the grave, rather than listen to the seasoned advice of Holkar to retire upon Ujjain and return back after recouping his forces. Having entrusted the ladies into the hands of Holkar, the Bhao threw himself on his enemies and was eventually overpowered by them.

The victors of the Panipat were struck with admiration at the heroic spirit of their Brahmin antagonists and ordered that the Bhao and his nephew should be given a burial befitting a Muslim. But the Rajput allies of the invader would not consent to disgrace their dead opponents by an unholy burial and threatened to fight a bloody battle if the bodies were not handed over to them. It was thus the Brahmin leaders of the Maratha Empire were given the last rites and honours of their own caste by their Hindu opponents.

The Bhakar concludes with the death of the Maratha Chiefs and does not at all refer to the Mutiny in the camp of the Durrani Chief, to the differences of opinion among his allies and the consequent fizzling out of their hopes of crushing for ever the Maratha oppressors from the South.

SECTION 2.

Kasi Raja Pandit, the author of the Persian history of events, and an employee of the Nawab of Oudh, accuses the

Marathas of stubborn pride[1] and states that the disaster of the Panipat was but a well-merited nemesis of their wilfulness and hauteur. One suspects that the writer must be moved by personal pique, consequent on a letter written to him by the Bhao, alleged to be lacking in formal respects[2] to the Pandit. Whereas the Pandit betrays his anxiety to exonerate his own master of all ideas of treachery and double dealing and adds that his defection to the side of the invader was but an afterthought. Such a historian is constitutionally incapable of absolute fairness in his treatment of the great personages and events of the Maratha side.

The Marathi and Persian accounts are agreed about the main outstanding events of the battle. That Ahmed Shah Abdali was assured of support by the North Indian Princes, that the Marathas were out-manœuvred and hemmed in the village of Panipat, that there were three indecisive actions followed by a final *coup de grace* ; that the Rajputs and Jats were either neutral or in secret sympathy with the invader and in the ultimate crisis Sadasiva Rao would not entertain ideas of retreat nor of peace with his enemies.

But the points of difference between the two authors are great, crucial and grave, requiring a restatement in the interests of historic truth. The Pandit accuses the Bhao of blind arrogance which spurned the wiser counsels of the veteran Holkar and Surajmal,[3] not to offer the invader the chance of a pitched battle. That the Bhao had no option but merely to obey the Peshwa when he entrenched himself near Panipat is proved by later history.[4] Besides, the Bhakar does not give any hint of the slightest misunderstanding[5] among the Hindu leaders and discovers the Holkar as always loyal to the core and Scindia would not flee for his life when advised by the Bhao to escort back the ladies of the camp. Instead, the Maratha General is pictured to be trudging[6] on foot among his followers, evincing great sympathy and solicitude for the sick and wounded among the rank and file in his army and not as an Orlando Furioso.

In the account of Kasi Raja, the Durrani Chieftain exhibits unbounded confidence in his abilities as a general and warrior who would not compromise his position by silly negotiations of peace or truce with the enemy[7] ; whereas Yadav Narayan refers to more than once of his anxiety to come to some understanding with the enemies.[8] This statement of the Bhakar receives additional support from the published Peshwa's papers.[9] It is found therein that Ahmad Shah was eager to come to some agreement with the warriors of the Deccan whose mettle he could appreciate better than the nerveless despots of the Hindustan.

The Pandit's account avers that the Bhao was almost supplicating the writer and his patron to intervene on behalf of the Marathas,[10] thus compromising the character of Sadasiva Rao as a leader of indomitable will and rare courage. This statement is given the lie direct by the Bhakar as well as by the discovery of an order to the Bhao to hold on and not to surrender.[11] In truth, Kasi Raja Pandit seems anxious to impress on the reader with his own exalted dignity and that such a personage was slighted by the thoughtless leader of the Marathas.

The Pandit exaggerates the rôle of his patron as a *Deus ex machina* when the Nawab is made to throw in his sword on the side of the invader with very little pretext for breaking away from the plighted word of friendship with the Marathas, and that the Durrani Chief was eager for the alliance[12] with the Nawab who was shown, later on, extreme marks of honour by the former. He is indeed taxing one's credulity when he asserts and writes[13] to the Peshwa also that the bodies of the two Maratha leaders could receive the Hindu rites of cremation only, by the intercession of the Nawab with the Afghan invader, by quoting previous history for argument and support. The several instances of the stuffed heads of Hindu leaders exhibited for the delectation of the faithful need not be repeated here. The alleged generosity of the Nawab is flatly contradicted by the Bhakar[14] which asserts that the Rajput and other Hindu allies of the invader were mainly responsible for the last honours shown to their Hindu antagonists.

In the ultimate analysis, it was a pyrrhic victory for the Northerners. The invader failed to follow up in the footsteps of the previous victors on the same field by usurping the insignia of the Delhi Empire and the Maratha strength was still unbroken. That was the main reason for the hasty retreat of Ahmad Shah Abdali rather than the story of mutiny by his own followers. Despite the disaster, the Marathas could not be dislodged from the vantage ground gained by them with the single exception of the Panjab. Their Viceroys still held on to Agra, Gwalior and Rajputana and were soon to inflict such condign punishment on the prime authors of the Panipat disaster, that the name of the Maratha would hush up even the crying children of Hindustan.

REFERENCES.

1. *The Battle of Panipat*, by Kasi Raja Pandit. Edited by H. G. Rawlinson, pp. 4, 52.
2. *Ibid.*, p. 14.
3. *Ibid.*, pp. 4, 7, 8.

4. *Peshwa's Dafter*, No. 21, pp. 202–03.
5. *Panipat Bhakar.* Edited by R. B. K. N. Sane, B.A., p. 58.
6. *Ibid.*, p. 38.
7. *The Battle of Panipat*, p. 28.
8. *Panipat Bhakar*, pp. 38.
9. *Peshwa's Dafters*, No. 2, pp. 142–56 ; No. 21. p. 215.
10. *The Battle of Panipat*, pp. 27, 30.
11. *Ibid.*, p. 63.
12. *Ibid.*, p. 12.
13. *Ibid.*, p. 42.
14. *Panipat Bhakar*, p. 64.

REVIEWS.

ALTERNATING CURRENTS.

By Leo T. Agger, B.E., published by Macmillan & Company, Limited, London, 1934. Price 5*s*.

Although the number of text-books on Alternating Currents is large, most of them have been written for the engineer and the student taking university or higher technical courses. They, therefore, not only deal with the subject more or less thoroughly but are also comprehensive in their scope. The present book is intended for the student reading for junior examinations in electrical engineering and therefore deals with the alternating current theory in an elementary way. However, chapters on the elementary principles of the alternator, the transformer, the induction motor and the more common A. C. instruments have also been added at the end of the book. The treatment throughout, though elementary, is very lucid and illustrated by a large number of very clear diagrams, while the numerous examples at the end of each chapter should be of great use to the student. The treatment is suitable for providing essential groundwork for an effective study of the subject, particularly to the student reading privately, and should also be useful to practical men concerned with the handling of alternating current circuits and simple machinery. For this purpose, it fills a want in electrical engineering literature and can be recommended.

THE CAMBRIDGE MODERN HISTORY—VOLUME I THE RENAISSANCE.

(Pp. xii+724, 1934.) Publishers, Cambridge University Press. Price 7*s*. 6*d*.

This is a cheap edition of the famous Cambridge Modern History, planned by the late Lord Acton. It is priced only 7*s*. 6*d*. and the whole set of 13 volumes costs only 90*s*., though the original edition costs 21*s*. per volume. This great reduction in price must enable even comparatively poor libraries to stock the whole set, as it is superfluous to say that no library is worth its name without a complete set of Cambridge Modern History. The get-up of the book is nice and the printing is bold. Even those libraries which already possess a complete set of the original edition may easily go in for a second set of this cheap edition, as there is a constant demand for one or other of the volumes of the Cambridge Modern History.

M. N. P.

FORCES AT WORK.

(AN INTRODUCTION TO SCIENCE, BOOK III.)

By Andrade and Huxley. (Basil Blackwell, 2*s*. 6*d*.)

This beautifully-produced little volume, designed to stimulate interest in the science of everyday life, is worthy of its distinguished authors, and should certainly achieve their object. It is one of four volumes which include both physical and biological sciences, and are to be used for a compulsory science course by boys and girls from the ages of 10 to 14 years. This volume comprises chapters on Electricity and Magnetism, Light, and both Inorganic and Organic Chemistry. It treats in a popular manner even the more advanced portions of Electricity and Magnetism, as for example Electromagnetic Induction which is given seventeen pages of detailed treatment.

It is packed with useful facts and illustrations and will no doubt appeal to all readers, even those with no aptitude for mathematics. Moreover it is desirable that all students before leaving school should acquire a good general knowledge of the more useful applications of all branches of science, such as would be obtained from a mastery of this book. At the same time one must guard against the danger of packing the boy's mind with too many unconnected facts ; it will be necessary for the teacher to develop his subject more logically and not to follow a book such as this too closely.

A. E. WALDEN.

OBSERVATIONAL GEOGRAPHY OF THE BRITISH ISLES.

By H. Hatch and C. R. P. Duckering. (Macmillan, 2*s*. 6*d*.)

This little book is an excellent guide to the student in developing his powers of observation of his own district. It is attractive in matter and form and contains many practical exercises requiring detailed observation and mensuration. Expert teachers should be able to adapt these exercises to Indian surroundings.

The book is divided into three sections, namely Physical, Human Activities and Regional. The second is particularly useful since it introduces the pupil to a practical knowledge of not only the industrial occupations of the British people, but also local government, social services, and the amenities of life. It thus links up the study of Civics with that of Geography.

It provides most stimulating reading and one wishes there were similar books available on ' India'.

A. E. WALDEN.

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The Half-Yearly
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RESEARCH AND INSTRUCTIONAL WORK IN EXPERIMENTAL HYDRAULIC LABORATORIES.

By Prof. K. D. Joshi M.A., B.E., M.I.E. (Ind.),
M.R.San.I. (Eng.), A.M.I.Struct.E. (Eng.).

The backwardness of our knowledge in the field of Hydraulics seems really incomprehensible when we consider the prominent part that water plays in almost every activity of our life—in our household, in the vegetable kingdom, in navigation, in artificial canals constructed ever since the dawn of antiquity, and in power development and generation. This lack of knowledge is attributable, perhaps, less to the slow development of the indispensable ways and means for investigating the flow of water, than to a distrust of the conclusions drawn from experience—a distrust which, unfortunately is well founded in some instances. Because, it has happened many a time that, on critical examination of some successful engineering work that is said to have stood the test of time, the achievement boils down to the mere fact that the structure has not failed. But, the pertinent question is whether the desired result could not have been accomplished *as well* and *at a much less cost* in some other more scientific manner and this test the work may not stand. Engineering is not merely building at random and with extravagance which even a lay man can do in a way, but, it is building in a scientific way and what is more important with the greatest economy. A well-planned and properly executed experiment in a laboratory, on the other hand, will reveal all errors. It would point the way to the better solution of a problem both from engineering and economical aspects, two considerations that are by no means always synonymous.

In the foreign countries, it is becoming recognised more and more widely that the launching of large hydraulic projects like dams, reservoirs, weirs, canals, hydro-electric schemes, river training and harbour constructions, etc., to name only a few, without previously testing out the design in a hydraulic laboratory, must be looked upon as hazardous and, in most instances, a wasteful procedure. Even in India the P. W. Departments of the Governments of Bombay, Punjab and U. P. have established large-scale hydrodynamic research stations in charge of highly paid and competent officers of Government and all big problems like the best location of head sluices in connection with the Barrage in Sind, the silt prevention in the Punjab canals, etc., are being referred to these Laboratories for solution. Valuable results have been achieved in many cases, which have enabled the works to be constructed cheaply and scientifically. A beginning has been made in our State by starting a Hydraulic Laboratory, though on a small scale, in the Engineering College at Bangalore. But, still, a large-scale Research Station located at places like the Krishnarajasagara or the New Chamarajendra Reservoir, where plenty of water could be made available, is a great necessity for the solution of all hydraulic problems in our State, which is justifiably proud of possessing very big reservoirs, numerous canals and a large hydro-electric generating station. Hydraulic Laboratories and Research Stations are not luxuries but indispensable necessities.

One of the greatest of Research Workers of all time has said "Experimentation never errs, only your judgment errs in anticipating results which experience does not confirm. Quite unjustly does man complain about Experience, accusing it with the severest reproach of being deceptive. Leave experience alone and direct such lamentations against your ignorance which permits you to be hasty in vain and foolish desires." Foresight demands that in experimenting with models we should never ignore the necessity of keeping in constant touch with natural phenomena and incessantly compare the model with the actually existing full-size conditions.

It must be recognised that all phenomena connected with the flow of water are of so involved a nature, that, in order to combine the results derived from experiments into laws--all our formulæ should, in the end, be nothing but paragraphs composing the eternal and invariable laws of nature—the maximum amount of care should be exercised. When we do not succeed in finding the true values of all the unknown quantities in an equation, we always have a way out of the labyrinth of inexplicable phenomena, through the use of "Coefficients". A large number of Engineers, in charge of the construction of hydraulic works, who invoke such "authoritative data", look upon such "Coefficients" as the "Laws of the Medes" and as dogmas of uncontrovertible and eternal value.

Research work in a Hydraulic Laboratory enables one to analyse phenomena which at first confront one as indivisible units, by dismembering them into their component parts, and to reveal their inter-dependence. The further the progress is made in this direction, the more clearly will it be recognised that "Coefficients" are merely the exponents of one's ignorance. An important task in every experiment consists in searching out the disturbing factors that operate to befog, more or less, one's view of flow phenomena. The proper understanding and interpretation of problems, together with the advancing knowledge resulting therefrom, seem possible only when such experiments are undertaken in full cognisance of the responsibility that rests upon the experimentor. Before translating the results of the research into mathematical formulæ it should be fully realised that in the majority of cases such formulæ are likely to be used without further thought, by numerous so-called practicing Engineers, whose pleas are the generally recognised authority of the theorist to whom such formulæ owe their existence. How seldom are the origin and limits of applicability of such formulæ looked into! It is only when the limitations of the formulæ are blandly disregarded, that disaster follows and distrust of experimental results becomes justified. The head of an experimental laboratory must, therefore, command, by his methods and procedure, unconditional confidence at all times. He must, therefore, not only master completely the scientific principles of Hydraulics, Hydrodynamics and Statics, but keep in constant touch with the requirements of engineering practice. He should, above all, know how to make the knowledge he has acquired from his experiments show an *economic value*.

In a number of instances, a way towards a better solution of problems occurring in engineering practice has originated in a University Laboratory. Such laboratories may be for instruction or research work. Sharply dividing lines cannot be drawn between these two classes of institution, though the one or the other class of work may predominate. In a University Hydraulic Laboratory like ours, the instruction work to the students must naturally predominate while in case of the Government P. W. D. Laboratories as at Lake Fife near Poona, the research work must take precedence. There is however, no reason why the two types should not carry out both types of work side by side and in fact it is being done. both here and at Poona. By means of demonstration with models, the power of observation of the students is sharpened. The University Laboratory, however, must not confine itself merely to this demonstration and instruction but afford facilities, to those qualified to do so, to develop the purely scientific side of the engineering profession by pursuing research work. In the foreign Universities of the present day, this fact has been widely recognised and it is becoming practically impossibe in their University Laboratories to keep pace with the large number of problems that are referred to them and are demanding solution. The need for establishing separate Government Hydraulic Laboratories is being felt there in an ever-increasing measure and I hope such an auspicious day will soon dawn in our State also.

How often does it not happen that we dare not cut loose from the so-called old and tried-out types of construction? In most cases, the "advantages" of such types appear to consist rather in their being old and familiar, than in their being tried and true. Thus, the orthodoxy, which dogs us in every walk of life, bars the way to betterment and it is very difficult to remove the eternal doubts that pursue these "Doubting Thomases". The expense and harmful after-effects growing out of possible failures of new methods are, therefore, so serious that the utmost carefulness on the part of the experimentor is justified. In many such cases of failure, slight alterations and greater care in evaluating results would have demonstrated unassailably the usefulness of these new methods, which, for want of the two, get their death-blow once for all. The responsibility of experimentors is, therefore, very great indeed.

There is one more point, which I must draw out for the attention of an experimentor. This is the extraordinary and unseemly haste in some cases, with which he wants to generalise and deduce from insufficient and inadequate data and to rush to print and, what he considers, fame. He does this sometimes of his own accord but many times being goaded on by his friends or superiors for the production of results of experimental work. The case of Koch, whose meritorious work in furthering the advancement of Hydraulic Science cannot be valued too highly, is a typical example to be followed on this point. While he was still alive his friends urged him to publish the results of his research work, which he was always ready to show and discuss at length. He, however, resisted this urging because he felt convinced that his experimental data should not be regarded as the last work in hydraulic knowledge. He would say that certain phenomena were not completely explained by his experiments and that the publication of such results might readily lead to the reaching of erroneous conclusions, We must fully realise that it is the Hydraulic Laboratory that would bring us nearer to the correct understanding of the natural processes than could any method of abstract treatment of such problems through pure Mathematics. Further, it must be realised in all humility, that with the widening of the circle of our knowledge, the points of contact of this ever-growing circle with the unexplored field, which lies beyond, are constantly increasing in number. For this reason, we must reject as unfounded that the growth in the number of Hydraulic Laboratories is ever likely to exhaust the number of problems to be solved by them. As Herbert Spencer, the great English Philosopher, who began his career as an Engineer, has well said "Positive knowledge does not, and never can, fill the whole region of possible thought." The greater the number and the larger the size of our Hydraulic Laboratories, the better for the Engineering Profession. There can never be too many.

There are in all probably not more than a dozen Hydraulic Laboratories in the whole of India. Out of these not more than about half a dozen, which are Government Laboratories, are doing purely research work directed towards the solution of specific problems of the several Irrigation Departments in India. The rest are University Laboratories intended for instructional purposes as well as research work on a small scale. Our Engineering College Hydraulic Laboratory is one of the latter type. It comprises the following :—A storage overhead steel tank, which can supply water for experiments, up to a maximum of 2 cusecs. There is also a balancing tank which controls and admits a constant discharge at a constant head to the experimental units. The water from the balancing tank is then admitted to the following units :—

(1) A Gibb's module, of capacity of about ½ cusec, which is a device very useful in irrigation canals for passing a constant discharge, even with a varying head in the parent channel, of course, within a certain modular range.

(2) A siphon of about ½ cusec capacity, which is of the type of the large scale one installed at Lake Fife near Poona. This device is the one which is going to be more general as automatic spill-ways of the future important reservoirs.

(3) A unit for the determining of the coefficient of discharge and velocity in case of different mouthpieces and adjutages.

(4) A Standing Wave Flume, which is a semi-module for purposes of measuring discharges passing through canals.

(5) Broad-crested weirs, for determining the coefficients of discharge in case of different types of weirs.

(6) Different types of notches, rectangular, triangular Cipoletti, etc., for determining the coefficients of discharge.

(7) Two measuring tanks for volumetric measurements, each of capacity of 250 cubic feet.

(8) A pumping unit for pumping back the water collected in the measuring tank to the overhead steel tank.

The Laboratory is about five years old, and during the last three years the following further progress has been made, since the year 1932 :—

(1) The storage tank capacity which was insufficient, has been now doubled, to a total of 12,800 gallons.

(2) The pumping capacity has been quadrupled, so that units of larger capacities could now be installed and fed.

(3) A Venturi Flume unit has been added to measure discharges by differences of pressures and velocities at the throat and entrance.

(4) A Float Recorder and Integrating Drum has also been now added to complete the Venturi unit mentioned above.

(5) An Amsler's Current Meter has been provided for measurement of velocities of water.

(6) A Pitot's Tube has been provided also for the same purpose as the above.

(7) The channels conducting water to the different units have been deepened and widened to carry larger quantities of water to the several units and a bigger 'V' notch for measurement is now provided.

(8) A unit for experimenting on weirs curved in plan with different curvatures and convex and concave upstream, has been provided and research work on these has been undertaken.

(9) A Kennedy's Gauge Outlet, a device for giving a constant supply of water, in spite of the variation of water levels in the tail channel, within a certain modular range, has been provided.

(10) Hook Gauges of the most accurate type have been installed.

(11) A Unit for measuring the coefficients of discharge under a varying head, through plug sluices and pipe

and masonry barrels, which are most common in case of our Mysore Tanks, has been installed.

(12) Vertical and Horizontal Vernier scales have been installed for calculating velocities of parabolic jets of water issuing from mouth-pieces.

Further, extensive additions, in the shape of a bigger standing Wave Flume, a battery of 4 or 5 different types of Automatic Siphon units, stilling ponds upstream and downstream of the above, a unit for the determination of the coefficients of rugosity in case of different types of channels, scale models of the Krishnarajasagara sluices, and also the deep level weir sluices at the New Chamarajendra Reservoir, are under contemplation of being installed in the near future as funds will permit. The Laboratory is yet young but in course of time promises to grow into a useful one both for instructional and research purposes.

THE GNEISSES AND GRANITES OF MOUNT JOY, BANGALORE.

By Charles S. Pichamuthu, B.Sc., F.R.S.E., F.G.S.
(*Department of Geology, University of Mysore.*)

INTRODUCTION.

The gneisses and granites of Mysore offer an interesting, if complicated, subject for study. Descriptions of these rocks are found scattered in various reports on local geology published in the *Records of the Mysore Geological Department*. These have been classified into four divisions, and they are from the oldest to the youngest named as follows :

1. Champion Gneiss.
2. Peninsular Gneiss.
3. Charnockites.
4. Closepet Granite.

Their general group characteristics are given by Smeeth,[1] Sampat Iyengar[2] and Rama Rao.[3] They are each of them considered to belong to a distinct epoch of intrusion.

The rocks in and near Bangalore belong to the Peninsular gneiss group. The term "Peninsular Gneiss" is used for a complex which includes many varieties of rocks. Bangalore is well situated for examining these rocks, for, practically within its limits, there are several quarries which expose to view different types of gneisses and granites with their accompanying aplite and pegmatite veins. The study is made more interesting because of the abundance of schist inclusions incorporated in these acid rocks, the ample evidences afforded of injection phenomena leading to the formation of *migmatites* and allied varieties of composite gneisses, and of contamination resulting in the development of hybrid rocks.

One of the most interesting quarries in Bangalore is that of Mount Joy,[4] near Basavangudi, and a description of this will serve to illustrate the complicated nature of the Peninsular gneiss. This hillock, which is known in the neighbourhood as Naraharirayara Gudda is a good starting point for the study of this complex, for, within a small compass, there are exposures of a variety of gneisses, granites and associated acidic vein material.

---

[1] W. F. Smeeth, "Outline of the Geological History of Mysore," *Bull. Mys. Geol. Dept.*, 1916, No. 6, pp. 15-19.

[2] P. Sampat Iyengar, "The Acid Rocks of Mysore," *Bull. Mys. Geol. Dept.*, 1920, No. 9, pp. 2-26.

[3] B. Rama Rao, "The Distinguishing Characteristics of the Champion Gneiss and the Peninsular Gneiss of the Mysore State," *Rec. Mys. Geol. Dept.*, 1935, Vol. 33, pp. 80-97.

[4] C. S. Pichamuthu, "The Petrography of Mount Joy Bangalore," Indian Science Congress, 1936.

The oldest rock in the area is the gneiss which because of its characteristic augen structure resembling grains of *sorghum* seeds on their stalks, has sometimes been designated "cholam" gneiss. This contains several basic inclusions. Associated with this type of gneiss, are the banded and streaky gneisses. Both these kinds of gneisses are intruded by granites which could be differentiated in the field, according to their textures, into fine, medium and coarse varieties. The coarse type occurs sometimes as inclusions in the fine. The rocks are traversed by granite and aplite veins. Of the granite veins, those disposed east to west are earlier, for they are intersected and sometimes displaced by the later north to south veins.

THE GEOLOGY OF THE AREA.

Augen Gneiss.—This occurs as caught-up patches in the granites. This is essentially a biotite gneiss with a specific gravity of about 2·73 which is higher than that of the associated banded and streaky gneisses. There are small inclusions of basic rocks which are composed chiefly of hornblende and plagioclase with plenty of granular titanite.

In thin section, the gneiss shows protoclastic granulation. Abundant shreds of biotite and hornblende, either unaltered or passing over into biotite, sweep round the porphyroclasts of felspar and quartz. A little epidote is present. Of the accessories apatite is very abundant and titanite subordinate. In suitable sections, the essentially migmatitic nature of this type is well seen. Some bands are composed of hornblende, plagioclase, biotite, epidote, titanite and magnetite. These represent the layers of the original basic schists. Alternating with these are bands which contain abundant microcline and quartz; this is the acidic material which has been injected into the schists. There is evidence that sometimes the crystalloblasts in the centres of the augen have grown *in situ* for the hornblende and biotite laminæ abut abruptly against them. Though in some cases these growing crystals have pushed the schistose laminæ apart, leading to the development of the augen structure, the writer considers that pressure has been the more important cause for the formation of the "eyes".

Banded and Streaky Gneiss.—This is a wide-spread type of rock in Bangalore, but there is not as great a development of this variety in Mount Joy as in some other parts of the town. It occurs here in somewhat oval patches. The rock is commonly grey or dark-grey in colour and has a specific gravity of about 2·68. The gneissic banding is very pronounced, the bands being often wavy and contorted. These do not contain schist inclusions of any size. The earlier schists have been torn into shreds or thin layers and the injection of acidic material in the form of aplite and pegmatite veins between these separated layers gives this gneiss also the general characters of a *migmatite*. While still a thick pasty mass, the rock has assumed a streaky character caused by magmatic movement as well as by pressure at depths. The influence of the pressure caused by expansion due to injection, is indicated by the occurrence of *ptygmatic folding* in the pegmatite veins which are at right angles to the direction of foliation.

Under the microscope these rocks also exhibit granulation. There is abundant felspar with no traces of twinning and with an index of refraction less than that of canada balsam. There is very little microcline. Biotite is the chief ferromagnesian mineral, but a little hornblende which is altering into biotite is present. Epidote occurs in minor quantities. Apatite in numerous minute crystals is the chief accessory.

The Granites.—The granites of Mount Joy could be distinguished into three types according to the texture exhibited by them. The coarse granite which forms the major part of the hillock is the earliest. Patches of these are found enclosed in the medium granite. Veins of a fine-grained granite cut through all the earlier rocks. The contact between these granites is quite sharp.

The granites, which are the prevailing rocks in this quarry, have caught-up patches of augen gneiss and streaky gneiss. There are also several inclusions of dark basic rocks.

The coarse granite forms the eastern portion of the hill. It contains hornblende crystals which are altering into biotites. This rock has been contaminated by the assimilation of basic xenoliths and the earlier-formed migmatites. The specific gravity of the rock is 2·67 which is slightly higher than that of the medium-grained granite whose specific gravity is about 2·65.

Slices of the coarse granite contain quartz, abundant fresh microcline, saussuritized plagioclases and broad plates of hornblende which are altering on the margins to minute flakes of brown biotite, with separation of iron. A little epidote is present.

The medium and fine-grained granites resemble the coarse in their mineralogical contents, but bear somewhat more quartz and microcline. The plagioclases are usually saussuritized, and when fresh can be identified as oligoclase. Biotite is common and hornblende is invariably altering into biotite. Myrmekite is of frequent occurrence; blebs and tongues of this project into microcline.

The fine-grained granites are the youngest and occur as veins intruding the other rocks of the area. All these veins are not of the same age as some of them intersect and displace others. Quartz, microcline and microcline-perthite occur abundantly. A little oligoclase is present which may be saussuritized; this mineral is sometimes included in the microcline crystals. Biotite and hornblende are the chief ferromagnesian minerals. The brown biotites are sometimes interleaved with a green variety. Micrographic and myrmekitic structures are common.

Aplite.—Thin veins of aplite are present. They are very acid differentiates of the granites and contain practically no ferromagnesian minerals. The specific gravity of the rock is about 2·54. They are composed mostly of quartz and orthoclase which does not show any twinning. A little albite or acid oligoclase, with an index of refraction less than that of canada balsam, is present.

Some of the veins are so acid that they are composed almost entirely of quartz.

Pegmatite.—Several veins of pegmatite intersect the granites. They are very coarse and contain big crystals of biotite or hornblende.

Basic inclusions.—As already mentioned a very interesting and characteristic feature of the geology of Mount Joy is the occurrence of numerous inclusions of basic rocks. There are more than thirty small irregularly shaped patches of these inclusions in the quarry, one of which at the northern end being fairly big. The specific gravity of these xenoliths varies between 2·9 and 3·1. These represent the unassimilated remnants of the original schists into which the granites and pegmatites intruded.

Under the microscope most of them are seen to be composed essentially of hornblende and plagioclase, and those inclusions which do not possess a schistose character could be described as plagioclase amphibolites. Hornblende alters into biotite, this change being bridged by the formation of a dark brown slightly pleochroic substance which does not possess the characteristic cleavages of biotite. The quantity of biotite varies; it is more abundant nearer the margins of the inclusions than in the interior.

The crystals of plagioclase are often seen to be more basic in the centre than in the margins. The interior of the crystals is decidedly more refracting than canada balsam, whereas the refractive index of the borders is almost equal to, or only just a little more than balsam. The centres show alteration, whereas the outer zones are quite clear. The zones are not clearly demarcated, but the extinction positions are different. As the result of this, when the stage is rotated between crossed nicols, the extinction zone is seen gradually to widen or narrow. This phenomenon is noticeable only in sections of the xenoliths taken from the margins and indicates acidification of the plagioclases due to the xenoliths being surrounded by a granite magma.

Titanite is an abundant accessory in the basic inclusions. This mineral is found as big granules or with the characteristic wedge shape. In thick sections, the grains are pleochroic from pink to pale green to colourless. In the micaized borders of the inclusions, apatite is more common. Epidote is frequently present. Of the iron ores, magnetite is more prominent than pyrites.

The complete conversion of these hornblendic inclusions into biotite schist is not seen in Mount Joy, but has been noticed by the writer in the Lalbagh Quarry. Excellent gradation specimens showing the various stages of this change can be collected from the quarry in the Intermediate College compound.

SUMMARY AND CONCLUSIONS.

Mount Joy is an excellent quarry for the study of intrusion and contamination. The sharp contacts between the various kinds of gneisses and granites, and the marked contrast in their structures, indicate considerable time intervals between the formation of each of these types of rock.

The augen gneiss and the banded gneiss originated by the intrusion of acidic material into the pre-existing schists aided by the effects of regional metamorphism. The augen gneiss is the earlier and the banded gneiss the later product of this progressive change. The coarse-grained granite was next intruded and it was after its consolidation that the medium and fine-grained granites were intruded, for the coarse variety occurs as caught-up patches in the finer rocks.

With such definite evidences of the successive formation of the component members of the Peninsular gneiss complex, it is rather difficult to consider all of them as belonging to one eruptive period, unless one imagines that the time of intrusion was so prolonged as to allow of the earlier formed material to consolidate before the later members were intruded. So long as this succession of intrusions is recognised, it does not really matter whether the gneisses and granites of Mysore are considered to be of four different epochs of intrusion or of only two; for, even in the Peninsular gneiss which is considered as a unit, there are evidences in Mount Joy that the constituent rocks were intruded at different periods.

Of the granites, the coarse-grained variety which is the earliest, has a high specific gravity. It contains more hornblende than the finer varieties. There is also more basic plagioclase in the coarser than in the finer variety, the latter being very rich in microcline. All these characters make it clear that it is a contaminated rock.

The succession of events here may be summarised as follows. Into the pre-existing basic schists, aplitic and pegmatitic material was injected resulting in the formation of migmatites. During this period the rocks were subject to regional disturbances. Then a granite with its pegmatites, intruded these rocks and assimilated blocks of migmatite as well as blocks of the original hornblende schist, and became contaminated. There is a progressive granitisation, and the later finer-grained varieties are typical biotite granites. The coarse veins of pegmatite cutting all the other rocks of the area, are the latest.

The writer is engaged in an intensive study of the gneisses and granites occurring near Bangalore and a correlation based on volumetric study as well as on the examination of the heavy mineral contents will shortly be published elsewhere.

EXPLANATION OF PLATE.

FIG. 1. Streaky gneiss showing the injection of parallel veins of aplite and pegmatite, resulting in the formation of migmatite.

FIG. 2. Irregularly shaped caught-up patches of streaky gneiss in granite.

FIG. 3. Photograph showing the coarse granite being intersected by veins of fine-grained granite (grey) and pegmatite (white).

PLATE.

FIG. 1.

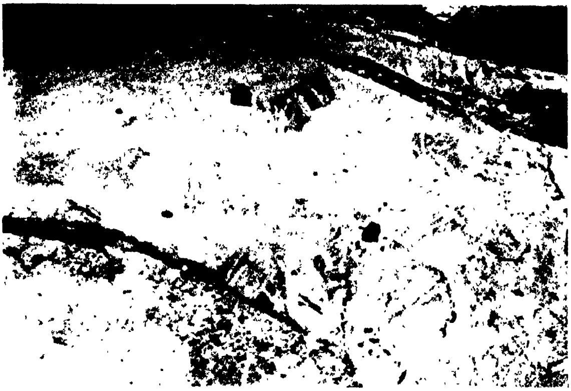

FIG. 2.

FIG. 3.

REVIEWS.

THE KADAMBAKULA: A HISTORY OF ANCIENT AND MEDIÆVAL KARNATAKA.

(By G. M. Moraes, M.A., with a Preface by the Rev. H. Heras, S.J., Bombay. B. X. Furtado and Sons, 1931, pp. xiii and 504 illustrations, maps and pedigrees.)

This bulky book is based on a thesis submitted to the University of Bombay and it was awarded the Chancellor's Medal. It is the fifth of the Series of Studies brought out under the auspices of the Indian Historical Research Institute, Bombay, and claims to be not merely the history of the Kadamba Dynasty, but a complete history of Kuntala or Western Karṇāṭaka, with stress laid on its administrative institutions and cultural features. Its chronological range is well over ten centuries, from the beginning of the 4th century down to about the middle of the 14th. The subject begins with the history of Kuntala in the pre-Kadamba epoch from the times before the Christian era down to the emergence of the Chūṭu Sātavāhanas who probably ruled from Vaijayanti. The legendary beginnings of the Kadamba line are interpreted to support the view that the dynasty was of indigenous origin and, in course of time, gained recognition as being of Brahmanical status. The author holds that the northern origin of the line was for the first time put forward in two grants of Harikēsari Dēva, dated 1053 and 1055 A.D., when it had emerged out of its three centuries of political eclipse; and the tradition of the migration of the Brahmans from Ahichchatra to the *agrahāra* of Sthāṇaguḍha and of their being the ancestors of Mayūraśarma's Brahmans is held to be lacking a sound historical basis, having no support in the early records.

The Kadamba alliances with the Vākāṭakas and the Guptas are explained by Mr. Moraes who supports the contemporaneity of Durvinīta, the son of Avinīta Ganga, Pulikēśi Chāḷukya and Bhogivarman Kadamba, as well as that of Avinīta with Ajavarma. The chronological scheme put forward is based on the assumption that Mayūravarma ruled about 345 A.D. when Samudra Gupta undertook his southern expeditions, and that about 80 years elapsed between the foundation of Kadamba rule and the accession of Kakusthavarma whose Palāśikē grant is dated in the 80th victorious year.

The next section of the subject deals with Banavāsi under Chāḷukya and other rule till the rise of the Hāngal Kadamba line under Irivabēḍanga and Chaṭṭa-dēva whose successors became independent sovereigns of Banavāsi in the

11th century, resisted strenuously and continuously the advance of the Hoysalas and became involved in the Kālachūrya usurpation of Chāḷukya rule at the close of the 12th century. Kadamba power contrived to survive even the shock of Malik Kafur's invasion; but its end was almost contemporaneous with that of the Hoysalas.

The Goa line of Kadambas ruled from Chandrapura over almost the whole of the Konkan and developed the town of Goa which subsequently became the capital in the time of Jayakēśi I. Malik Kafur is believed by our author to have overrun the seacoast of the Konkan as far as Rameśvar, *i.e.*, *Cabe de Rama*, South of Goa and further, Ferishta's "Prince of Ma'abir" is equated with the Kadamba ruler who made a defensive alliance with the Hoysala, Baḷḷāḷa III. Ibn Batuta's "Sindabur" is likewise equated with Chandrapura.

The minor branches of the family that wielded rule in Bayalnāḍ, Bēlūr, Bankāpur and Nagarkhand are supplemented with another branch of the stock that ruled in Kaḷinga with the *cognomen*, Khēḍi. Their fief of Panchavishaya is equated with a portion of the Mandasa estate in Ganjam. In evaluating the cultural contributions of the Kadambas, Mr. Moraes attributes emphatically a non-Āryan origin to the phallic cult which prevailed in the land alongside of the Nāga-worship. Abundant epigraphic testimony is brought to bear on the Kadamba administrative institutions, particularly as regards revenue resources, the status and power of the feudatories, details of military organisation, educational and charitable endowments. The technique of warfare is partly based on the study of sculpture reliefs and friezes of war scenes on the assumption that these latter were strictly true of the sculptors' own days. The *agrahāra* of Tāḷgunḍa is detailed; corporations of this variety comprehended sometimes Bauddha and Jaina *Maṭhs* and *Brahmapuris* (settlements of learned Brahmans). The earliest specimens of Kadamba architecture are held to be derived from the primitive structures of the Āndhrabrityas. The architectural development has been traced, from the primitive *basti* at Hālsi through subsequent stages to the finished Kamala Nārāyaṇa temple at Dēgāmvē. The influence of the Goa-Kadamba sculptures on the Hoysala art is noticed. There is an exhaustive list of localities noticed in the epigraphs supplemented by a notice of the extent of the kingdom. Perhaps it is a large claim for the Kadamba coins to say that they marked a definite stage towards the emergence of obverse and reverse legends on coins. A few unpublished inscriptions are given at the end with their English translations. The documentation is perhaps a trifle too elaborate.

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